metal
atment

Vol. 26 : No. 170 NOVEMBER, 1959 Price 2/6

The illustration shows a Furnace for continuous treatment of ferritic or austenitic steel strip. Installed at the Stocksbridge Works of Samuel Fox & Company Limited, Sheffield.

We specialize in the design and construction of:-

Open Hearth Furnaces
Soaking Pits of all types
Continuous Multi-zone Bloom and Slab Re-heating Furnaces
Continuous Bogie type Ingot and Slab Heating Furnaces
Furnaces for Aluminium Melting, Coil Annealing and Slab Re-heating
Forge and Heat Treatment Furnaces
Stress Relieving Furnaces
Shipyard Plate and Bar Furnaces
Modern Lime Burning Kilns

PRIEST FURNACES LIMITED · LONGLANDS · MIDDLESBROUGH
also at TELEGRAPH BUILDINGS HIGH STREET SHEFFIELD

PRIEST
The last word in Furnace design

F. 144

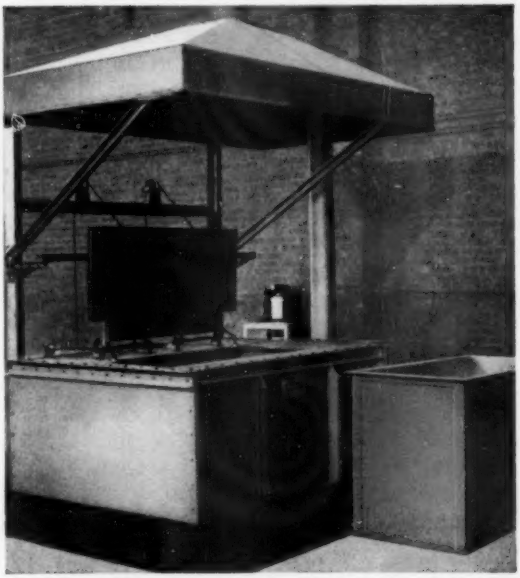

Brosius
manipulator
150 Brosius Manipulators now in use throughout the world carry out all the manipulation necessary during forging, saving manpower and time.
The smallest Manipulator will handle pieces up to 2,000 lb. in weight. A wide range of designs are available, the maximum being suitable for pieces up to 20,000 lb. in weight.
THE HEAD WRIGHTSON MACHINE CO LTD
COMMERCIAL STREET · MIDDLESBROUGH
LONDON · JOHANNESBURG · TORONTO · SYDNEY · CALCUTTA

P.3359

'FULLOAD' Heat Treatment Furnaces

Maximum efficiency with minimum fuel consumption. The unique exhaust flue arrangement in the bogie hearth ensures speedy heating of the load, constant temperature in the furnace and the elimination of cold areas in the heating zone. We supply furnaces for all purposes and all fuels, batch type or continuous. For further particulars ask for leaflet 47.

Photo by courtesy of Messrs. Lloyds (Burton) Limited



SALT BATHS and HOT AIR BATHS

For the solution treatment of aluminium alloys. Temperatures correct to within 3°C. Our Salt Baths and Air Recirculating Furnaces fulfil the most stringent specifications and conform to all A.I.D. requirements. We can supply Quench Tanks and all other ancillary equipment. We design the Furnace to suit our customer's requirements.

CRUCIBLE TYPE?

MAINS FREQUENCY? MEDIUM FREQUENCY?

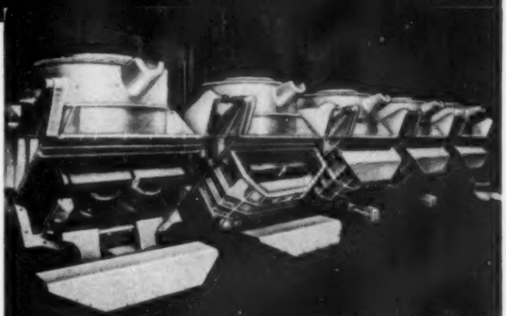
CHANNEL TYPE?

GWB DEMAG

INDUCTION MELTING FURNACES

can offer you the best of either type

Five Demag 1 Ton Low Frequency Induction Melting Furnaces for copper and copper alloys.



There are no set rules for choosing any one particular type of melting furnace since, even with the same metal, production requirements may swing the choice to one or the other. With access to the wide range of designs and long experience of Demag, pioneers in Induction Melting Furnace development, G.W.B. are now equipped to advise on the most suitable unit to suit a particular charge and specified production programme. For ferrous or non-ferrous induction melting, furnace designs are available covering:

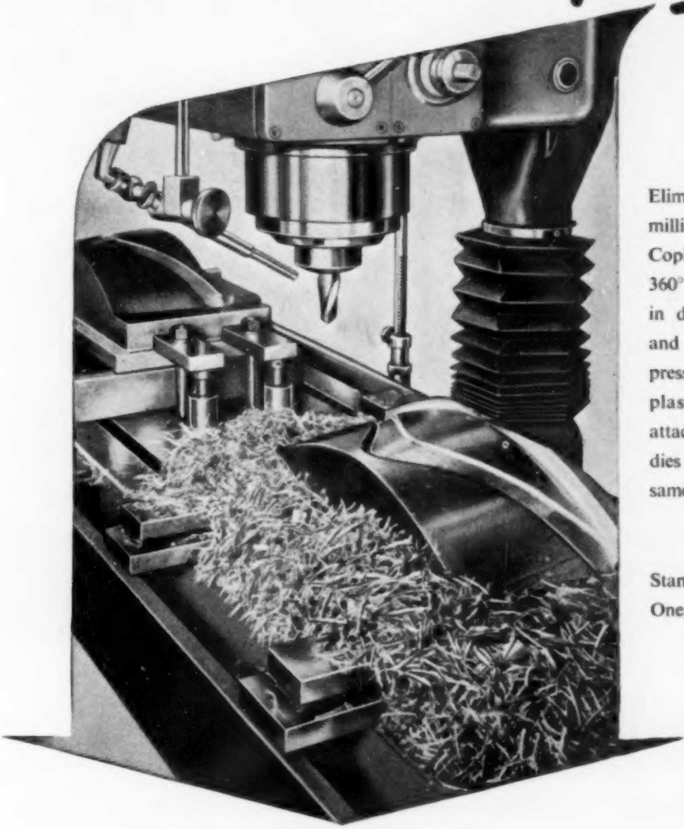
> **Crucible Type Furnaces for Mains Frequency or motor alternator operation, for steels, irons and non-ferrous metals.**
>
> **Channel Type Mains Frequency Furnaces for melting light metals, copper and copper alloys, zinc and irons.**

The electric induction method of melting can solve your melting problem, and G.W.B. can help you in choosing the correct induction furnace.

G.W.B. FOR ALL THAT IS BEST IN ELECTRIC MELTING AND SMELTING FURNACES

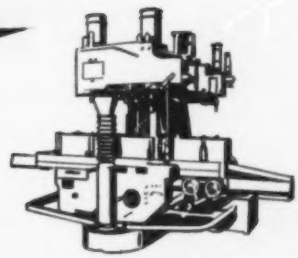
GWB **G.W.B. FURNACES LIMITED**
P.O. BOX 4 · DIBDALE WORKS · DUDLEY · WORCS. *Telephone: Dudley 55455*
Associated with Gibbons Bros. Ltd. & Wild-Barfield Electric Furnaces Ltd. G.W.B. LDS

Make your Die Sinking *Automatic*



Eliminate the human element by copy milling and die sinking the 'Rigid' way. Copies vertical angles up to 90° and 360° profiles with any number of changes in direction without circular table and with constant feed. Light feeler pressure permits the use of wood or plaster for masters. Reverse image attachment enables top and bottom dies of either hand to be made from the same master.

Standard table sizes up to $92\frac{1}{2}$" x $25\frac{1}{2}$"
One, two, four or six spindles.



—By INSTALLING

SWISS **RIGID**

AUTOMATIC HYDROCOPYING MACHINES

Send for the illustrated brochure to Sole U.K. Distributors

DOWDING & DOLL LTD
346 KENSINGTON HIGH STREET, LONDON, W.14
Telephone WESTERN 8077 (8 lines) Telegrams ACCURATOOL HAMMER LONDON

141


It's
"H.T 1"
from experience!

November 1959

Vol 26, No 170

metal treatment

and Drop Forging

Editor D. J. O. BRANDT B.SC., A.R.S.M., F.I.M.

Assistant Editor F. D. GRIMMER

Advertisement Manager J. M. DICKIE

Production Manager R. J. LOVELL

Publisher H. J. DWYER

Scottish Area Manager T. H. SMITH

Official organ of the
NATIONAL ASSOCIATION OF DROP FORGERS AND STAMPERS

President J. H. SWAIN
Director A. L. STUART TODD, C.B.E., J.P.

Grove Hill House, 245 Grove Lane
Handsworth, Birmingham 20
Telephone NORthern 3311-3

Published on the 15th of each month by

AN INDUSTRIAL NEWSPAPERS PUBLICATION

INDUSTRIAL NEWSPAPERS LIMITED

John Adam House
17-19 John Adam Street
Adelphi, London W C 2
Telephone TRAfalgar 6171 (10 lines)
Telegrams Zacatecas, Rand, London

Subscription Terms Home and Overseas 30*s* per annum prepayable
Single copies 2*s* 6*d* (3*s* 0*d* post free)

CONTENTS

This journal is devoted to metals—ferrous and non-ferrous—their manufacture, properties, heat treatment, manipulation. testing and protection, with research work and development in all these fields

Drop forging and research

THE need for keeping abreast with technological development raises a difficult problem for the small firm. Major research efforts are difficult if not impossible for such firms, and the most they can hope to do is employ one or two qualified scientists to study new trends and advise on existing processes in the light of up-to-date knowledge.

Solutions to this problem have varied considerably in different countries, but in the U.K. and in Germany the co-operative research association has been found to provide a practical answer to many of the difficulties. These organizations cover well over half of industry in this country, and provide well-equipped research facilities for finding answers to problems of common interest to the particular industry and at the same time for giving advice to the individual company. Research cannot be done cheaply, and the great advantage of this scheme is to make access possible to a lot of information at a price, which, being shared, is within the reach of any firm.

This leads to the important and thorny question of how much money should be spent on research by an industry. The Federation of British Industries has suggested that industrial firms should spend 1-2% of turnover on research. It is obvious that new and expanding industries, such as the plastics industry for example, have had to spend a far greater proportion of their turnover on research than have the traditional industries. The very fact that the traditional industries have had a lead over those more recently developed by virtue of many years' practical experience has tended to result in a standing still of some of the older industries in the face of growing competition from more aggressive newcomers. It is noteworthy that the zinc and lead producers, particularly in America, have recognized this fact and are substantially increasing their research programme at the present time.

In view of this, it is particularly encouraging that there is now real hope that the British drop forging industry will also have its own co-operative research association. This was announced by Mr. J. H. Swain, president of the National Association of Drop Forgers and Stampers, at the annual banquet held in Birmingham on November 5. In the course of his speech Mr. Swain made the following remarks:

'During the last two years our Technical Committee has been giving very serious consideration to the desirability of this Association embarking upon a long-term programme of Scientific and Technical Research on similar lines to that which is being carried out by so many industries in this country and abroad.

'It is now more than 40 years since the first co-operative research association was set up in the U.K. on a voluntary basis. In the intervening time the movement has grown until today 46 research associations are in being serving different industries with a total income of about £7,000,000 per annum, a significant proportion of which is provided by Government grants, negotiated through the Department of Scientific and Industrial Research.

'The programme of investigation by our Technical Committee has included visits to a number of leading research laboratories and discussions with eminent scientists and

directors of research, such as Sir Charles Goodeve of the British Iron and Steel Research Association, Dr. Vernon of the Department of Scientific and Industrial Research, Dr. Sully of the Steel Castings Research Association, and many others.

'During these visits and discussions we have learned that most of the industries which are competitive in product to drop forging have well-established research organizations. These have proved of considerable benefit to their members, moreover, they have expanded from time to time and widened their field of activity.

'The outcome of these cautious and conscientious studies by your Committee is that they have now put forward a definite recommendation that the NADFS should sponsor the formation of a research organization for the benefit of the whole drop forging industry; this was approved by our Governing Council at a recent meeting. We are, therefore, empowered to carry the project a stage further at an early date.

'The decision is that the NADFS as the only co-operative body serving our industry, shall sponsor the formation of a research organization which is to be entirely independent of our Trade Association.

'It will be open to all members of the drop forging trade, and other firms who have a stake in our industry, such as plant manufacturers, certain suppliers and possibly large users of our product.

'We have already had some encouraging discussions with Sir Charles Goodeve and it is now our intention to open serious negotiations with BISRA with a view to the Drop Forgers' Organization becoming a satellite or lodger unit operating at the Sheffield Laboratories of BISRA.

'If we can come to a satisfactory arrangement, and we believe we can, the Council of BISRA has already agreed in principle to our proposals, we shall have the benefit of the facilities and experience of that vast organization, but with our own Research Council to direct our investigations.

'This autonomous research organization is to be financed by a separate levy on the participants and we confidently expect that it will qualify for a generous revenue grant from the Department of Scientific and Industrial Research. Therefore, the cost to those who join should be quite modest in relation to the prospective benefits.

'I am convinced that this proposition should be given full support by all enlightened firms who are connected with drop forging because I am sure that the enormous advances which are now being made in the application of science and technology to industry make it imperative for us to move with the times and move quickly.'

There is little that we can add to Mr. Swain's statement except to urge the firms eligible for membership to ensure that this plan becomes a reality as soon as possible. If the drop forging industry were concerned only with maintaining its position in this country it would be important enough, but in view of the urgent necessity of offering high-quality low-price British goods abroad it is vital.

Vacuum heat treating

A review of applications, techniques and furnace equipment

F. J. BECKET

The suitability of available furnace equipment and techniques for various applications of vacuum heat treatment of metals is discussed. The author is with the Vacuum and Induction Heating Division, Wild-Barfield Electric Furnaces Ltd.

THE APPLICATION of high vacuum to metal heat treating techniques has developed rapidly in recent years, largely as a result of the demands of the aircraft and nuclear engineering industries. Vacuum brazing of honeycomb sections, the annealing and degassing of titanium are examples of uses made of vacuum in the aircraft field, while zirconium and uranium annealing, and beryllium sintering are now commonplace nuclear engineering applications.

Fundamentally, heat treating in vacuum gives the following advantages:

(1) A very pure protective 'atmosphere' is obtained under easily reproducible conditions. Since all interspaces are evacuated, the 'atmosphere' is uniform throughout the work.

(2) Undesirable impurities are evaporated. For example, high vapour pressure constituents such as cadmium, magnesium and manganese.

(3) Chemical actions dependent upon temperature and pressure are accelerated by vacuum processing. The use of vacuum also assists the dissociation of oxides, nitrides of iron, cobalt, nickel and chromium at relatively low temperatures.

Techniques

The principal vacuum heat treating techniques are brazing, sintering, hardening and annealing. These processes are each reviewed briefly.

Brazing The technique used is similar to that for hydrogen brazing. Capillary flow is accomplished more readily, usually without the need for fluxing the surfaces to be joined. Nickel-chrome alloy vacuum brazing of stainless steel honeycomb sections is an example of how an improvement in technique is possible by the use of vacuum. Brazing in hydrogen is often unsatisfactory where it is difficult effectively to purge the work. This is particularly true of honeycomb sections, and poor brazing can occur at interfaces where insufficient purging is obtained.

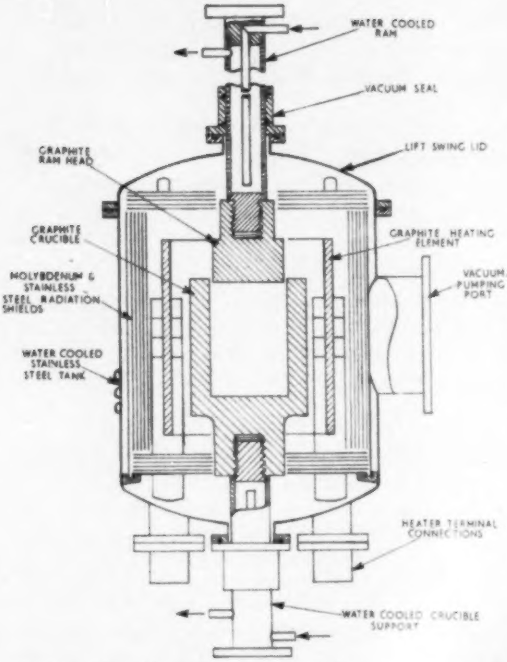
Improvement in strength is also obtained from vacuum brazed joints. Tests by Gyrogak and Fransico[1] on samples nicrobrazed in vacuum, salt bath and hydrogen, showed shear strength values of 63,000, 48,000 and 42,000 lb./sq. in respectively.

Furnace temperatures for nickel-chrome brazing are in the range 1,150—1,200°C. and vacuum pressures of $0{\cdot}1$—10μ (10^{-4}—10^{-2} mm. Hg) are used with hydrogen back filling to about 100μ as the work approaches temperature, in order to avoid excessive vaporization of the brazing alloy.

A more recent vacuum brazing technique is described in a UKAEA report on high temperature graphite joints, using a titanium cored copper-silver eutectic melting at 950°C.[2] For higher temperature joints zirconium, melting at 1,800°C., is used as the braze metal.

In planning vacuum-brazing work the vapour pressure/temperature characteristics of the materials must be considered. Also, if the furnace is to be used for processes other than brazing requiring higher operating temperatures, contamination of molybdenum radiation shields by, for example, chromium vapour, can result in a molybdenum/chrome eutectic forming on the innermost radiation shield. The melting temperature of this shield would then be about 1,650°C. In a well designed furnace it should be possible to change over sets of radiation shields when changing from one type of process to another.

Sintering Sintering of powdered metal compacts is an ideal application of high vacuum heat treating. The fine particles have relatively large surface areas which absorb gas. During heat treating these gases are driven off, leaving the particle surfaces



1 *Graphite resistor, internal element furnace for hot-press sintering of beryllium*

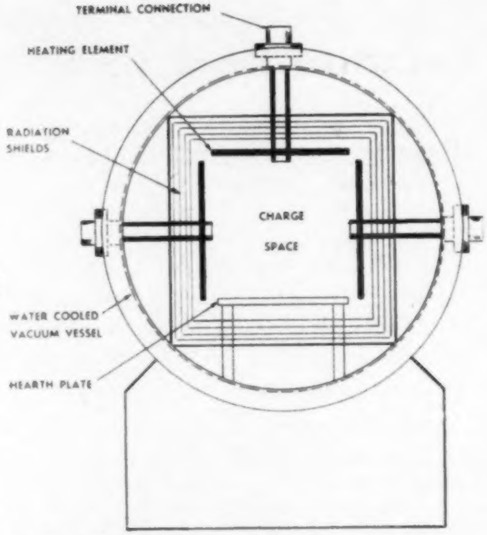
clean, resulting in high compact strength. A wide range of powder metallurgical materials is now being vacuum sintered, including beryllium, tantalum and tungsten. Fig. 1 shows schematically a furnace design for hot pressing beryllium compacts while sintering at 1,200°C. in a vacuum of 10^{-4} mm. Hg.

Hardening The least developed of vacuum heat treating applications, hardening presents a difficult work handling problem where quick quenching has to be carried out after heating.

Obviously the usual quenching media, air, oil and water, cannot be located in the vacuum chamber, but a second chamber, connected by a vacuum valve to the furnace chamber, can be used to contain the quench medium.

Practical difficulties arise from the time delay between moving the charge from the furnace into the quench chamber, and sealing off before vapour from the quenching medium can contaminate the furnace heating elements and heat shields.

For slow quenching, the technique is simplified to one of transferring the work to an adjoining watercooled chamber and backfilling the chamber with an inert gas to accelerate the transfer of heat from the charge to the chamber walls.



2 *Internal element furnace—schematic*

In internal element furnaces where the thermal mass is low relative to volume, it is possible to achieve rapid rates of cooling within the furnace chamber, by back filling with inert gas after switching off power.

Commercially, the advantages of vacuum hardening have not as yet matched the high initial cost of the equipment, and to the author's knowledge few vacuum quench furnaces have been built.

Annealing The annealing of stainless steel, titanium, zirconium and uranium parts in vacuum results in good ductility and clean surface finish. Titanium is both annealed and degassed for the removal of hydrogen in the one operation. Some of the largest vacuum furnaces in the U.S.A. were constructed for this application with charge capacities up to 10,000 lb. of sheet titanium.

Typical annealing temperatures and operating vacuum pressures are given in Table I.

TABLE I *Typical annealing temperatures and operating vacuum pressures*

	°C.	μ
Stainless steels:		
Austenitic	1,050—1,100	1·0—10
Martensitic	750— 850	0·1—1
Titanium	730— 750	0·1—1
Zirconium	900— 950	0·1—1
Uranium	600— 700	0·1—1

The continuous vacuum annealing of stainless steel strip is an obvious development. Commercially, the method should prove economical since

no additional surface treatment is required following vacuum heat treating. Technically, the problem of sealing the vacuum chamber against the moving strip does not present an insurmountable obstacle, and several avenues of investigation would appear feasible. Among these, a series of vacuum sealing rolls through which the strip passes on entry into, and exit from, the furnace. Alternatively, liquid seals are a possibility and a preliminary investigation of this method suggests that a refrigerated mercury bath could be used as a seal.

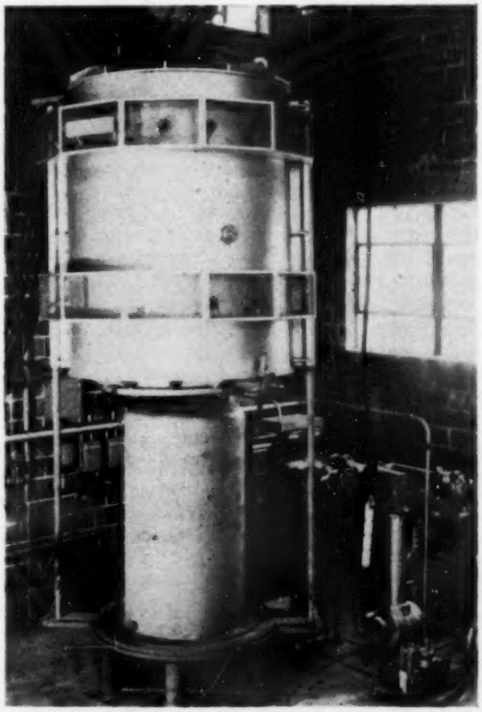
Closely allied to annealing, the stress relieving of welded stainless steel assemblies can also be carried out in vacuum to ensure that maximum strength and ductile properties are retained without the risk of pick up causing embrittlement of the welds.

Furnace equipment

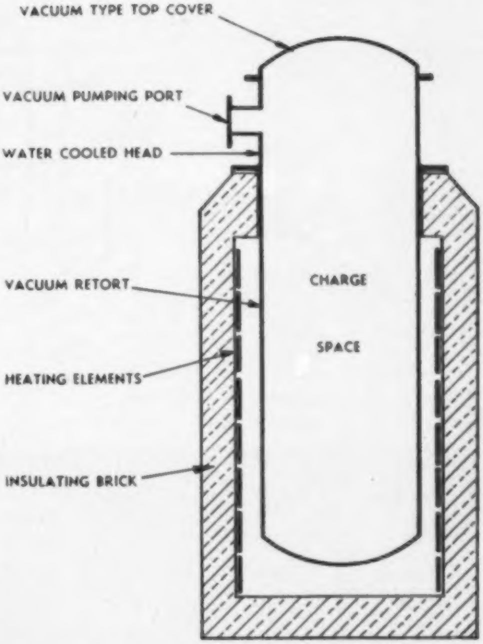
The principal factors to be considered in choosing suitable vacuum furnace equipment are:

(1) The charge size and shape.

(2) Temperature requirements and accuracy of control required.



3 *Vacuum bell furnace—hot retort type*



4 *Hot retort pit furnace—schematic*

(3) Heating cycle requirements, *e.g.* loading, heating, holding, cooling, unloading times, and production rates.

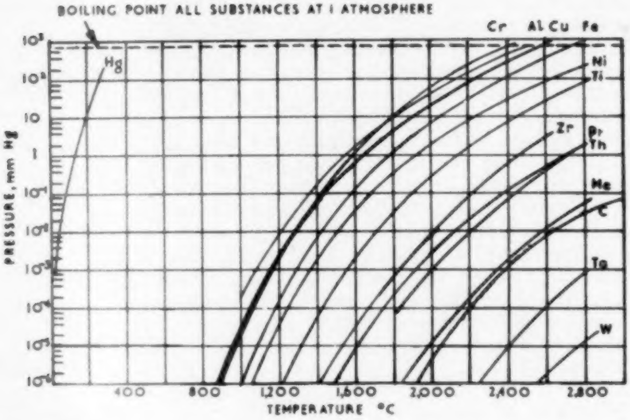
(4) Furnace atmosphere requirements, *i.e.* operating vacuum pressure, inert gas purging, etc.

From an analysis of the answers to these questions, an equipment specification designed to meet the process requirements by the most economical methods can be prepared.

Types of furnaces There are two distinct types of vacuum resistance furnaces—hot-retort and cold-retort (or internal element). Many variations are possible, but fundamentally the equipment is designed either, so that the charge is contained within a vacuum-tight retort and is heated externally, or, the retort is made as a vacuum tank and the charge, heating elements and thermal insulation are all contained within it. Figs. 2 to 4 show various vacuum furnaces which fall into one or other of the basic types mentioned.

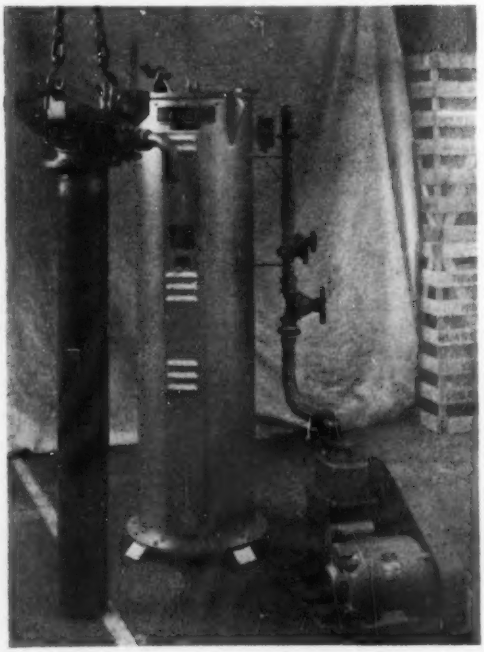
Hot-retort furnaces such as the pit-type furnace illustrated in Fig. 4 are basically conventional brick insulated furnaces to which a vacuum-tight retort and pumping system are added.

Probably more vacuum heat treating has been carried out in furnaces of this type than any other. This is due to it being relatively cheap to build



5 RIGHT *Vapour pressure against temperature*

6 BELOW *Pit type, hot retort furnace*



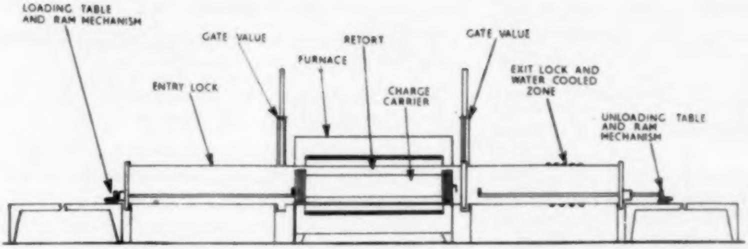
them complete, or to adapt existing furnaces by adding the vacuum retorts and pumping systems.

Hot-retort, pit-type furnaces are used at temperatures up to about 1,000°C. and vacuum pressures down to 10^{-5} mm. Hg. For all but the smallest types of furnace it is usual to make the retort from nickel-chrome alloy such as Nimonic 75. In vacuum heat treating the retort design has to be considered from two aspects: (1) The mechanical strength of the retort material at temperature is important since there is a pressure equal to one atmosphere surrounding the retort; (2) the vapour pressure of the alloy constituents must be considered relative to the operating temperature.

Referring to the vapour pressure/temperature curves shown in Fig. 5, chromium has a vapour pressure of about 5×10^{-5} mm. Hg at 1,000°C. This temperature is also near the limit for retorts from a mechanical strength viewpoint. Thus, to avoid rapid deterioration of the retort the operating vacuum pressure should always be maintained above the critical value for the retort material. Also to relieve the retort of atmospheric pressure at elevated temperatures, the furnace and brickwork can be evacuated to a pressure of about 5 mm. Hg, thus transferring the stress from the retort to the cool outer casing of the furnace.

A small rotary gas-ballast pump is used to maintain coarse vacuum on the outer chamber. Where quick cooling of the charge is required, the retort can be back filled with inert gas, then disconnected from the vacuum system and lifted from the furnace on to a cooling rack. By using this technique several retorts can be used with a single furnace. While the first charge is cooling, the second can be lowered into the furnace and a third retort can be loaded. Fig. 6 shows a vacuum pit-furnace design for annealing uranium fuel elements at temperatures up to 700°C.

After pumping down to 1 mm. Hg the retort is back filled with argon to a pressure of several millimetres. To accelerate cooling of the charge the retort can be lifted from the furnace. In this design the retort is connected via a vacuum valve and flexible bellows to a fixed vacuum pipe connection to the rotary pump, via a second valve. When disengaging the retort from the pumping system both



7 *Schematic arrangement of semi-continuous vacuum furnace*

valves are closed, the bellows connection is air released and disconnected from the retort by undoing clamps. The retort is then lifted on to a cooling rack and there connected to a second vacuum pumping system. The second retort can then be lowered into the furnace and a new heating cycle commenced.

Bell furnaces In hot-retort furnaces the work is positioned in an open hearth mounted on the furnace base. The retort is lowered over the charge to rest against a vacuum seal on the base flange. Finally the furnace bell is lowered over the retort.

Although more costly to build than the pit-type furnace, bell furnaces have certain advantages. Access to the work base can be at floor level, which helps considerably the arrangement of work prior to lowering the retort, and it is thus undisturbed during positioning of the retort and furnace.

To accelerate the cooling cycle, the furnace bell can be lifted off. Hence, a single bell can be used with a number of retorts and bases. While overhead lifting gear is required for handling the bell, retort and charge, a pit is not essential; an important consideration when planning a heat-treating installation for existing buildings.

Limitations on temperature and vacuum pressure are the same as those for pit-type hot retort furnaces.

Horizontal hot retort furnaces Horizontal hot retort furnaces are built in a wide range of sizes for applications ranging from laboratory sample annealing and sintering to large-scale tube- and sheet-annealing furnaces. In principle, the vacuum retort replaces the muffle used in atmosphere furnaces. Vacuum connections are made from one, or both, ends of the retort which extends beyond the furnace proper. Watercooling of the end sections protects the vacuum seals. Auxiliary equipment includes a cooling zone and power-operated loading table.

From this design it is a short step to the semi-continuous furnace, which is the logical method for vacuum-annealing stainless steel rod, bar and tubes in quantity production. Such a furnace is shown schematically in Fig. 7. The equipment consists of a loading table, entrance zone, furnace zone, cooling zone and unloading table. A system of air-operated vacuum gate valves enables successive charges to be moved from the entrance zone through the furnace to the cooling zone. The charge carrier is moved by a power-driven ram mechanism located on the loading and unloading tables.

Automatic control of a semi-continuous process cycle is quite feasible, the work transfer mechanism, vacuum valves and atmosphere controls being interlocked to the furnace programme controller.

The advantage of vacuum-annealing stainless steel products is primarily that of eliminating subsequent surface treatments, such as pickling or buffing to remove the discoloration which often occurs when hydrogen-atmosphere annealing. A comparison of total processing times and operating costs suggests that semi-continuous annealing is already commercially attractive, the higher initial capital cost of the vacuum equipment being outweighed by lower running costs, and the improved quality of the finished product.

Summarizing on hot-retort furnaces generally, two factors emerge which govern their application. Basically, the temperature limit is determined by the hot strength of the retort material and its vapour pressure *v.* temperature characteristics. Secondly, the charge vapour pressure *v.* temperature must be given consideration to avoid contamination of the retort alloy by vapour deposits.

For practical purposes the nickel-chrome alloys give a useful temperature range up to about 1,000°C. at vacuum pressures down to 10^{-5} mm. Hg.

Metals such as molybdenum, tungsten and tantalum, while having superior hot strengths and vapour pressure characteristics than the nickel-chrome alloys, are extremely difficult materials to work in any but the very small sizes of retort and, in any event, are far too costly to justify their use as retort materials.

Cold-retort or internal-element furnaces The commercial development of the cold-retort furnace has grown from the many and varied laboratory requirements for vacuum metallurgy, operating at temperatures above the 1,000°C. limit imposed by hot-retort-type equipment. The principle of their design is illustrated in Fig. 8, which shows a horizontal internal-element furnace chamber. The heating-element system is located immediately

around the charge and thermal insulation, in the form of radiation shields, is provided between the element system and the water-cooled tank forming the retort.

Advantages gained by this design include a choice of several high-temperature heating-element materials, such as molybdenum, tungsten, tantalum or graphite. In vacuum, heat transfer from the heating elements occurs mainly by radiation of heat and reflecting heat shields provide an effective means of minimizing heat losses from the furnace. Heat loss that does occur is 'collected' on the water-cooled retort, usually constructed of stainless steel or mild steel. Heating element connections are brought out through vacuum seals to water-cooled terminals.

In the furnace illustrated, the heating-element system consists of three graphite panels supported on posts of the same material. Alternatively, molybdenum or tungsten rod or strip elements can be used, the choice being that of selecting materials compatible with the work at elevated temperature under vacuum conditions. Radiation shields can be formed from thin sheets of molybdenum, tungsten or tantalum, depending upon the operating temperature.

Furnaces of this type are used for vacuum heat treating applications such as nickel-chrome brazing, annealing, sintering and degassing, and temperatures in excess of 2,000°C. can be obtained, the practical limit being one of heating element design and the vapour pressure *v.* temperature characteristic of graphite (about 2,500°C. at 4μ pressure).

Raising the operating pressure by back filling with argon or hydrogen enables higher ultimate temperatures to be achieved, thereby maintaining the furnace pressure above that of the vapour pressure of the heating element, but radiation heat losses increase proportionately to the fourth power of temperature, and the temperature limit would appear to be about 2,500°C. using existing designs embracing metal radiation shields. Future development, however, may trend towards composite insulation systems, consisting of reflecting shielding and low-conductivity insulation. In such a furnace the atmosphere would be controlled to suit the process requirements and also the high-temperature vapour-pressure characteristics of the heating-element and radiation-shield materials.

As a near example, a graphite element furnace with carbon insulation can be operated to temperatures of 3,000°C. after evacuation and subsequent admission of pure hydrogen, which is bled into the furnace at a controlled rate while the vacuum pumping system operates. In this way a continuously changing atmosphere is maintained at reduced pressure.

Vacuum pumping systems

A vacuum furnace pumping system should meet the following basic requirements:

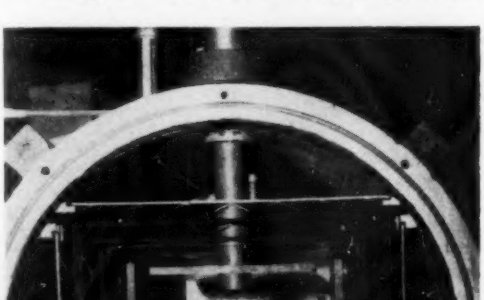
(1) Initial evacuation of the retort to the operating vacuum pressure should be reasonably fast.

(2) Adequate pumping capacity should be available to handle the gas load throughout the furnace cycle.

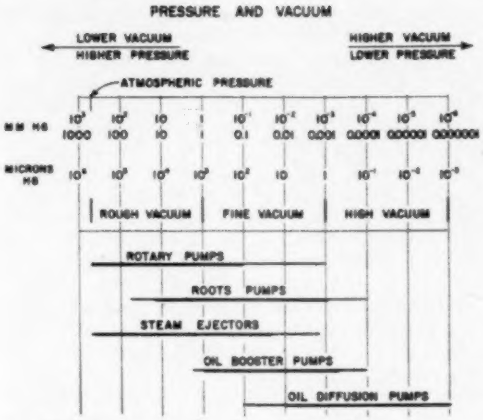
(3) Control and instrumentation of the system should be planned for ease of operation.

Types of pumps Fig. 9 illustrates schematically the pressure ranges covered by mechanical pumps, oil vapour pumps and steam ejectors. A brief description of each type of pump is given, but for a more detailed treatise the reader is referred to more specialized literature.[3, 4]

Rotary pumps Oil-sealed rotary vane or rotary piston pumps are used for evacuating the system from atmospheric pressure down to about 100μ (0·1 mm. Hg), *i.e.* to within the operating pressure range of oil booster and diffusion pumps. Both rotary vane and rotary piston pumps are now fitted with a gas-ballast feature which overcomes the effects of water vapour (from the system being evacuated) condensing in the pump, and contaminating the oil. The term rotary gas-ballast



8 *Horizontal graphite resistor furnace—internal element type*



9 *Operating pressure range of various types of vacuum pumps*

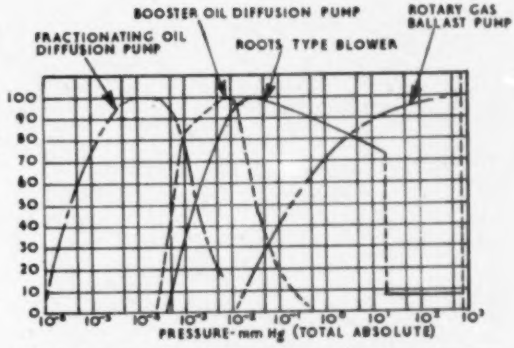
pump is generally used to describe both the rotary vane and rotary piston pumps of this type.

Roots-type mechanical-booster pumps Roots pumps operate on the principle of fast rotating lobes producing a high gas displacement relative to pump size. The lobes are unlubricated and the fine running clearances make it necessary to operate the pump on a reduced pressure to avoid overheating, which would occur at atmospheric pressure. The operating range is between 15 mm. Hg and about 10μ. A rotary gas ballast pump is used to back the Roots pump.

Oil vapour pumps Oil vapour pumps fall into two main types, fractionating oil diffusion pumps and booster oil diffusion pumps. Fractionating pumps operate over the pressure range 100μ—0·001μ (10^{-6} mm. Hg), reaching peak speed at or near 0·1μ pressure.

Oil-booster diffusion pumps operate over the range from about 800μ to between 0·1 and 0·5μ with a peak speed between 1 and 10μ.

Steam ejectors The steam ejector operates from atmospheric pressure to about 10μ, and thus is unique in being the only type of pump capable of operating at high speed over this wide pressure range. Of simple construction and low initial cost, the steam ejector is particularly suited to the larger types of vacuum-processing equipment such as furnaces for the stream degassing of steel, where high gas displacement is required over a vacuum pressure range from 100—500μ. A disadvantage from the operating viewpoint is the necessity of providing a steam generator if there is no existing steam supply. This factor very often outweighs any advantage gained in the lower first cost of the ejector, compared to a rotary gas-ballast pump and



10 *Percentage of maximum speed as a function of pressure for important types of high-vacuum pumps*

oil-vapour pump combination of similar capacities.

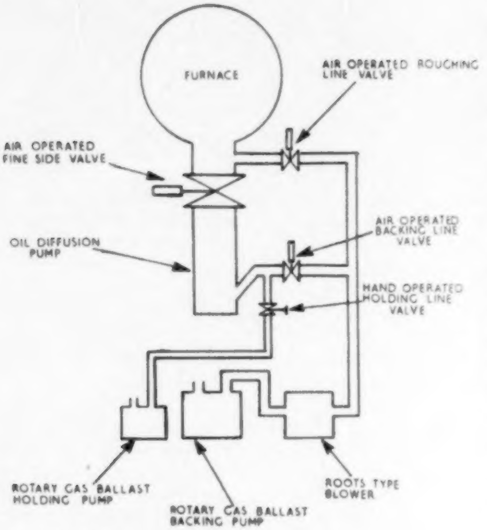
Pump selection Since most vacuum heat-treating processes require vacuum pressures in the micron range a rotary gas-ballast pump is usually employed in combination with either a booster or fractionating oil-diffusion pump, depending on the working vacuum-pressure requirements and the expected gas load. Fig. 10 illustrates diagrammatically the relationship between vacuum pressure and speed of the various types of pumps described above. From these curves, which are drawn to show percentage of maximum speed and are not, therefore, comparable in magnitude, it is seen that in selecting a pumping combination to operate the furnace at a particular pressure it is necessary to consider the characteristics of the process to ensure that the retort can be held at the desired operating vacuum even though the gas load may vary considerably during the cycle.

In the case of a vacuum sintering furnace which is to operate at 0·1μ pressure, a fast initial pump down is required in addition to the capacity to pump off a considerable throughput of gas drawn from the work-pieces during the heating cycle.

Dealing first with the operating pressure of 0·1μ. A fractionating oil-diffusion pump will be required to maintain this pressure and handle the gas load at temperature.

A rotary gas-ballast pump can now be selected to provide an adequate pump down time for the retort and to back the diffusion pump.

The weakness of the pumping system in this case is the intermediate pressure range between 1 mm. Hg at which pressure the efficiency of the rotary pump begins to fall, and the 20—50μ pressure range where the fractionating pump efficiency increases rapidly. Due to the high rate of gas evolution from the compact during initial heating, it is necessary to use an intermediate range pump such as a booster oil diffusion, or Roots blower to



11 *Typical vacuum pumping system*

prevent stalling of the fractionating pump during gas bursts from the charge. Alternatively, larger sizes of fractionating and rotary pumps can be used so that, despite the poor efficiency over parts of the pressure range, the throughput is still adequate. Usually this procedure is both uneconomical and, from the design viewpoint, undesirable.

Fig. 11 illustrates schematically a pumping system for a process such as sintering in which a fractionating pump, Roots blower and rotary pump are used. The additional rotary pump holds vacuum on the diffusion pump while the furnace is rough pumped.

Power supplies and temperature control

Selection of power supply and temperature control equipment is decided upon such factors as:

(1) Heating-element operating-voltage requirements.

(2) Accuracy of temperature control necessary.

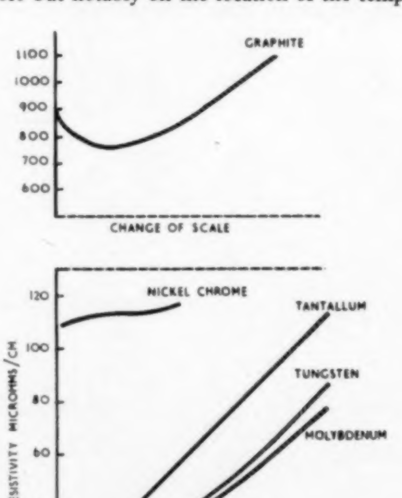
(3) Type of control; manual, semi-automatic or fully automatic programme control.

Heating elements For hot retort-type furnaces the heating elements are normally formed from nickel-chrome strip, rod or wire and designed to operate direct from 3-phase mains voltage. Where the furnace is double pumped, however, it is necessary to operate the element system at reduced voltage—usually 100 V.—to avoid voltage breakdown due to glow discharge phenomena when operating under reduced pressure. In this case, and where the element cross-section dictates the use of reduced voltages, a stepdown transformer is used.

Heating-element materials for internal-element furnaces are molybdenum, tungsten, tantalum and graphite. Fig. 12 shows the resistivity *v*. temperature characteristics together with that for a typical nickel chrome resistance alloy. In the case of molybdenum, tungsten and tantalum, there is a considerable increase in resistivity with increase in temperature. The electrical circuit must, therefore, be designed to avoid excessive load currents when switching on a cold furnace. Methods used to counter the problem include Star/Delta switching of the heating element winding, the use of variable transformers, tap-changing transformers and saturable reactors with a time delay circuit to override the normal voltage control of the resistance winding.

Control circuits For small furnaces a simple variable transformer or saturable reactor circuit gives satisfactory manual control of temperature, which is indicated on a millivoltmeter-type instrument from a thermocouple or radiation sensing head.

The simplest form of automatic control consists of a controller which switches the contactor coil circuit to give on/off control. The degree of accuracy achieved is dependent upon a number of factors but notably on the location of the tempera-



12 *Resistivity against temperature for Mo, W, Ta, Cr, and Ni-Cr*

ture sensing device and the thermal inertia of the work and retort.

Proportioning control using saturable reactors gives smooth stepless control of power and is used where very accurate automatic control is required. A typical circuit, including manually set time delay override of the magnetic amplifier output to limit the furnace power input during a predetermined warm up period, is shown schematically in Fig. 13.

While operating temperatures of 2,000°C. and above are common, the accurate measurement and control of temperature becomes difficult outside the range of thermocouples, *i.e.* 1,600°C. for platinum/platinum-rhodium. Radiation sensing heads, operating on the thermopile principle, are satisfactory so long as the furnace sight port remains free from metallic vapour from the charge condensing on the sight glass.

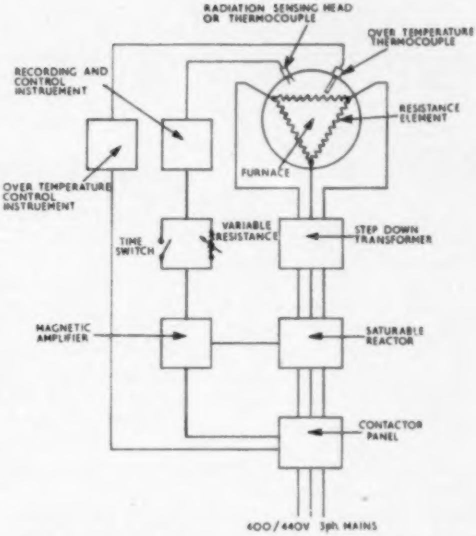
The most promising answer to the problem lies in the development of very-high-temperature thermocouples or resistance thermometers. Tungsten/rhenium thermocouples have been used for measuring temperatures in excess of 2,400°C.[5] and these are now becoming commercially available in this country. Tungsten or molybdenum resistance thermometers can also be used in a bridge circuit calibrated to indicate temperature.

Conclusion

This review of vacuum heat treating techniques will, it is hoped, serve to illustrate that furnace equipment is now available to meet the needs of industrial as well as laboratory applications.

At present, vacuum heat treating is applied not only to processes that can only be carried out by this medium, but also, to improve processes that were of necessity formerly carried out in controlled atmosphere furnaces. Future applications will undoubtedly be directed towards utilizing semi-continuous and continuous furnaces, already quite feasible from the design and manufacturing point of view.

Economically, comparing vacuum furnaces with protective-atmosphere equipment, it is often cheaper to produce a vacuum than to maintain a pure protective atmosphere. In first cost, however, a vacuum equipment is higher than conventional gas-atmosphere furnaces of similar capacity. For a true comparison to be made, the fast heating and cooling cycle of vacuum furnaces must also be taken into account as, very often, a small fast operating vacuum furnace can do the work of a larger batch furnace requiring long heating and cooling times. Once this aspect of furnace selection has been decided in favour of using vacuum equipment, the problem is simplified to deciding which type of vacuum furnace will be best suited to the process in question.



13 *Block diagram showing resistance furnace with saturable reactor control*

References

(1) G. A. Gyrogak and A. C. Fransico, 'Preliminary investigation of the properties of high temperature brazed joints processed in vacuum or in molten salt.' N.A.C.A. report 3450, May, 1935.

(2) R. Aves, D. Barnes, T. A. J. Jaques, and F. Wade, 'High temperature graphite joints.' A.E.R.E. report R/M 165.

(3) A. S. D. Barrett and M. E. Harper, 'Selection of pumping systems for vacuum metallurgical processes,' *J. Inst. Metals*, March, 1959, Paper 1904.

(4) C. M. Van atta. Kinney Manufacturing Co., 'The design of high vacuum systems.'

(5) C. T. Sims, *et al.*, 'Investigations of rhenium for electron-tube applications.' Battelle Memorial Institute.

Cold extrusion

The maximum extrusion pressure can be greatly reduced by pre-forming a cone on the head of the billet. With a 60 deg. cone angle on the billet and a 60 deg. conical die entry, the pressure needed to extrude copper rod is 28% less than that required to extrude a normal cylindrical billet through the same die.

This is one of the conclusions from the first stage of an investigation of the cold extrusion of steels and non-ferrous metals under impact conditions. The work is being carried out to see in what ways the varying ram speed of a crank press affects the extruded product in comparison with extrusion in a hydraulic press, where the ram speed is constant throughout its stroke. The pressures required to produce a given reduction in aluminium, copper and brass were found to be similar to those needed in a hydraulic press at slower speeds.

Successful extrusions were carried out at large reductions from unheated billets—in most cases the limit of reduction seems to be imposed by the maximum permissible stress in the punch.

Further information is given in *M.E.R.L. Plasticity Report* No. 138 (Cold extrusion of metals. Part 6—Under impact conditions, by M. T. Watkins and J. McKenzie), available from the Mechanical Engineering Research Laboratory, East Kilbride, Glasgow.

Application of electron microscopy

Effect of cold working on the block structure of aluminium

DASA HRIVNAKOVA

An electron microscope study carried out at the Welding Research Institute in Bratislava and reported in Hutnické Listy, 1959, (7). *The present English version is the eighth of a series illustrating the role of the electron microscope in metallurgy*

THE PRESENT WORK is concerned with observation of the effect of cold working on the nature of the block structure of pure aluminium by means of an electron microscope. The experiments were conducted with 99·999% Al material in the initial cast state and after recrystallization. The recrystallized material was produced by 80% reduction of the cross-section of the specimens with subsequent heat treatment for a period of 2 hours at 500°C. An electron microscope was employed in view of its great depth of focus and powers of resolution. As specimens carbon extraction and oxide replicas were used. The oxide replicas were given preference owing to the simplicity and speed with which they can be prepared. The experimental work was carried out in the electron microscope laboratory at the Welding Research Institute in Bratislava.

Preparation of specimens

The specimens were ground by the method normally used for metallography, with a particle size of the emery paper of 4/0. Electrolytic polishing was used, so that there would be no possibility that a mechanically-polished surface layer might distort the results of the observation. For the electrolytic polishing an electrolyte based on $HClO_4$ was used.

The block structures of the polished specimens were in some instances etched in accordance with the method of Fischer,[1] by the combined action of HCl, HNO_3 and HF, in which the main part in the revelation of the block structure, *i.e.* the separation of the surfaces of the cubic blocks, was played by HCl. For the preparation of good specimens the first essential is cleanliness of the surfaces to be examined. For this purpose, immediately after etching the specimens were lixiviated, and then washed in alcohol, acetone and benzene. The carbon extraction replicas were obtained by vertical vaporization of a thin layer of carbon film on to the polished surface. For vaporization of the carbon two carbon electrodes were used of 4-8 mm. dia., which were gradually brought towards each other. One of the electrodes has a conical point, while the other is flat. A sufficiently thick film is produced at a voltage of 30 V., a current of 20-50 amp., and after a vaporization time of 2 secs. The distance between the polished specimen and the carbon electrodes is 20-25 cm., and carbon is deposited at an angle of 70-80 deg. The method of preparation is basically the same as for steels.[2] The separation of the carbon film was carried out by two methods: separation in a 10% solution of HCl in alcohol, or by amalgamation. The second process proved to be more rapid, but was unsuitable for these replicas owing to partial decomposition of the specimen. After thorough washing the replicas were hung up in a drier, and subsequently made ready for observation.

In this work, however, oxide replicas obtained by anodic oxidation were used for the most part. Of the electrolytes used the most satisfactory proved to be a 3% aqueous solution of tartaric acid with the addition of ammonium hydroxide, so that the resultant *pH* value was 5·5, with negligible solvent properties.[3, 4] It should be borne in mind that electrolytes containing H_2SO_4 are unsuitable because they form a non-continuous layer of aluminium oxide. Good results were obtained by the use of a lead cathode with a distance of 2·5-3 cm. between the cathode and the anode. The advantage of the electrolyte indicated is the ability to control the thickness of the oxide layer by the voltage used; here it is a matter of a direct relationship: 1 V. $\sim$ 14 Å. For different types of microscopes (according to the size of VN in the

electron discharge tube) it is possible to form the most suitable thickness of the oxide film. The time required for the formation of this layer is approximately 5 mins., although the greatest part of it is formed in the first 20-30 secs. In his study of the accurate control of the thickness of amorphous oxide films formed in the same electrolyte, Haas[4] produces information in diagrammatic form to confirm this fact. Since the layer of Al_2O_3 acts as an insulator, on the other hand it is possible, by following the fall in the current between the anode and the cathode, to determine when oxidation is complete, since the current then remains steady at a definite minimum value.

The oxide film is removed from the specimen in such a way that it is divided up into small particles of suitable size and immersed in a saturated solution of $HgCl_2$ with the surface under examination upwards. Amalgamation lasts for not more than 5 mins.; the small particles rise and float on the surface. In order that the replicas shall not be excessively contaminated with the products of the chemical reaction between Al and $HgCl_2$, and in order that the specimen shall not be excessively disintegrated, it is desirable to cover all the remaining faces of the specimen with a layer of collodion or lacquer before amalgamation.

After separation of the particles, the specimen is lixiviated, and the particles are washed off in distilled water. After washing several times in a 10% solution of HCl, the latter are removed and placed in a drier. After drying they are prepared for electron microscope observation.

The thickness of the film is constant in the direction of the normal to the surface, and so, since the surfaces of the blocks are situated at different angles to the plane of grinding, their effective thickness for the passage of the electron beams will vary. It is not therefore necessary to shadow these replicas.

The block structure

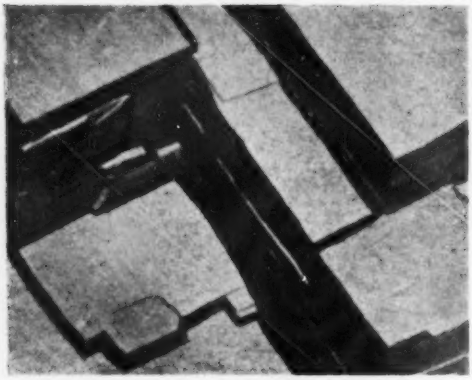
In a polycrystalline material the crystal is considered to be the basic unit of the whole crystalline mass. More accurately, a special X-ray study[5] has shown that the structure of the lattice is not homogeneous, but is made up of zones with a constant ordering of the atoms, the orientation of which is slightly different from the proper orientation of the grain. It is therefore a matter of a distinct irregularity in the change in the orientation of the lattices. By means of various reagents it is possible to reveal various more or less distinguishable sub-lattice formations, the size and formation of which are approximately the same in each lattice. Apart from the block structure already described, it is a matter of a sub-lattice or domain structure. Umanskii[5] makes mention of a block structure in the interior of sub-lattices, which would mean that it is not a matter of identical formations.

Hunter and Robinson[6] studied the extremely fine sub-lattice structure of aluminium of various purities, which had been revealed by chemical etching. They followed the effect of cold deformation, and thereby revealed a remarkable similarity in the behaviour of the lattices and sub-lattices during deformation and recrystallization. They explained the relative difficulty of detecting the sub-lattices by the relatively minimal distortions of the lattices along their boundaries by comparison with the boundaries of normal grains. From the point of view of the structure of these sub-lattices there are two important factors: the great number of sub-lattices forming the boundaries of the ordered lattices, and the fragmentation of the sub-lattices as a result of cold deformation. Qualitatively this agrees with the results subsequently published of a study of the block structure. Indeed, although for instance Welsh[7] denies that the sub-lattice structure revealed by electrolytic etching represents regular incoherence of the lattice structure, on the other hand the results published earlier express the fact that though not directly, such a structure definitely gives indirect expression to the relationship governing the energies in the inside of the grain. The fact that Welsh discovered sub-lattices which were different both in structure and size subject to different conditions of polishing (mainly different potentials) merely indicates that the combined effect of the parameters responsible for their formation are unknown at the present time. There exist various methods of calculating the size of the blocks. By X-ray methods, from the width of the lines the size of $0 \cdot 4\mu$ established by the method of Williamson and Hall agrees in order with the size of the blocks of aluminium which were observed on the electron microscope.

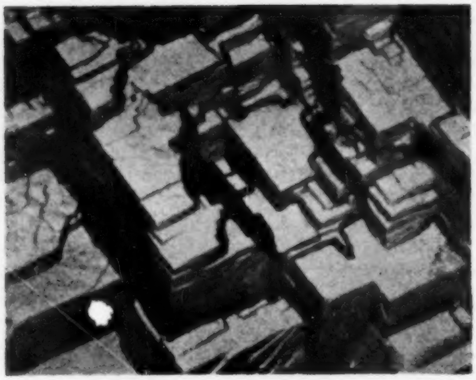
Likewise Ovsienko and Sosnina[5] studied the dimensions of blocks of cast Al single crystals and found that as the rate of growth increases, so also the addition of molten alloying elements promotes refinement of the blocks.

If we consider the size of the blocks as determined by X-ray methods to be absolute, then it is possible by comparison with the values revealed to find at all events an empirical conversion factor for each set of concrete etching conditions. In the instance under examination the agreement is good (1 to 4 $\times$ 10^{-5} cm.), so that the conversion coefficient may be taken to be unity.

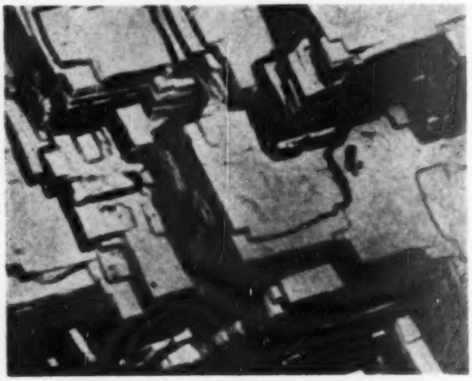
Since the number of blocks changes according to the state of the energy factors of the material, the density of the blocks can also be a gauge of this state, as well as of the strength properties of the material. Bragg[5] established that here it is a



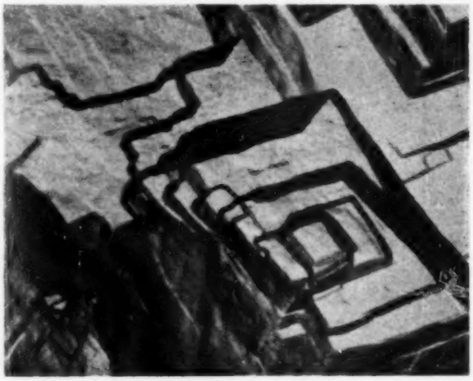
1 *Block structure of recrystallized aluminium.*
Oxide replica × 10,000



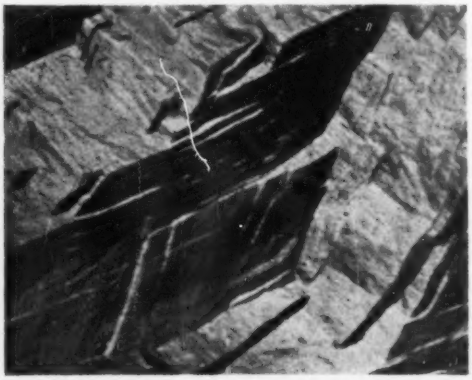
2 *Block structure of recrystallized aluminium.*
Oxide replica × 9,000



3 *Block structure of aluminium in the cast state.*
Oxide replica × 9,000



4 *Cast aluminium after 50% deformation.*
Oxide replica × 9,000

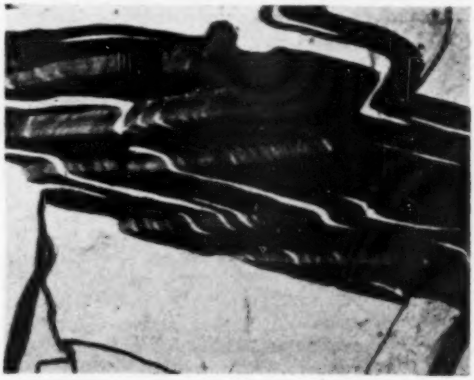


5 *Cast aluminium after 50% deformation.*
Oxide replica × 9,000

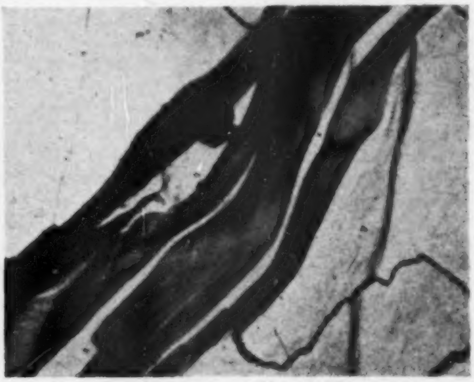
6 *Cast aluminium after 80% deformation.*
Oxide replica × 9,000

7 *Recrystallized aluminium deformed by shearing. Oxide replica* × 9,000

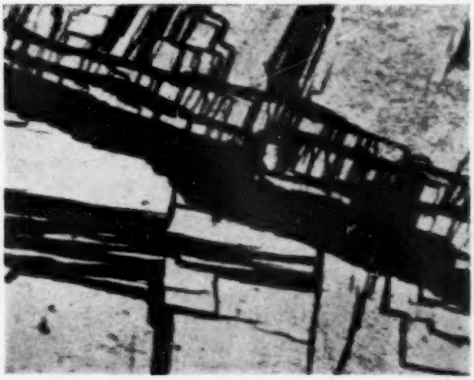
8 *Recrystallized aluminium deformed by shearing. Oxide replica* × 9,000



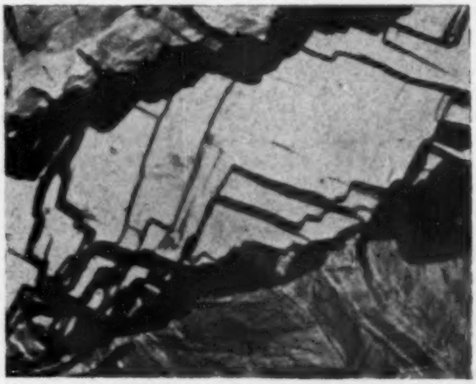
9 *Block structure of cast aluminium after deformation. Carbon extraction replica* × 9,000



10 *Block structure of cast aluminium after 40% reduction of the cross-section. Carbon extraction replica* × 10,000



11 *Grain boundaries of aluminium after recrystallization heat treatment. Carbon extraction replica* × 10,000



12 *Recrystallization zone of cast aluminium after 50% deformation. Carbon extraction replica* × 10,000

matter of an indirect relationship. Similarly to the principle of the theory of dislocations, the angle of disorientation of the blocks is a measure of the energy content or of the change in energy. Finally, in addition let us recall the hypothesis of Umanskii[8] that the fragmentation of the blocks is dependent on the gradual growth in the hardness of the material during ageing. As is evident, the study of the properties of the block structure is of practical importance from the aspect of the strength properties of metals.

Experimental results

The electron microscope investigation of the morphology of the block structure of 99·999% Al was conducted on material in the cast and recrystallized states, and on both of these after deformation.

So far as pure recrystallized aluminium is concerned, after etching of the block structure perfect cubic blocks were discovered with sharply defined faces running parallel to each other (figs. 1 and 2). A fundamentally similar block structure, apart from slight irregularities in the surfaces of the blocks, is possessed by the cast material (fig. 3). After the deformed specimens had been etched the effect of the deformation on the shape and size of the blocks was manifested in two different ways. One of these is actual deformation of the blocks, without changing their size, combined with their mutual disorientation. This effect is revealed in figs. 4 and 5. The disorientation of the blocks had been observed and measured by various X-ray methods. Since in an electron microscope only one small area of the surface under observation is available at one time, it is not possible to determine the angle of disorientation by measurement, but only to restrict oneself to verification of its existence. At the present time, therefore, there is no possibility of combined control by either of the methods.

At a higher degree of deformation, fragmentation of the blocks took place in the areas of maximum creep of the material, evidence of which is given in figs. 6-8. In fig. 6 it is possible to perceive both the effects of cold deformation side by side. It is difficult to establish the degree of deformation at which one or the other of these phenomena occurs, since the experiments were conducted with polycrystalline material, so that the orientation of the deformation force relative to the system of slip planes of the various grains was different. Approximate quantitative assessment of the size of the blocks provided good conformity with the results obtained by X-ray methods,[5] on the premise that the value obtained by X-ray methods is relevant to a definite small area of the material. This provides further confirmation that the existence of the block structure is a real phenomenon of the internal inhomogeneity of the individual grains. Apart from this the nature of the block structure is an indication of the abundance of the dislocations from which it originates.

Since by etching and positive shadowing of specimens after deformation it was impossible to reveal the slip bands or slip surfaces of the blocks, the procedure was carried out the other way round (*i.e.* by negative shadowing). Fig. 9 gives evidence of a system of slip surfaces equidistant from one of the boundary surfaces of a deformed block. A fundamentally different nature is shown by the slip surfaces in fig. 10, where the slip runs in two systems of slip planes. A more detailed study of this problem would require some simplification of the conditions of deformation.

The grain boundaries after etching of the block structure show above all irregularity in the change in the orientation of the blocks (fig. 11). Apart from this, the phenomenon of the increased energy content of the boundary zone is the fragmentation of the blocks, which exists in a narrow zone along the grain boundary. Remarkable is the inclusion of a recrystallization process (fig. 12), which manifests itself as a fundamental reconstruction of the block structure.

Conclusions

In this work, photomicrographs are shown which illustrate the effect of cold deformation on the block structure of pure aliminium. The results show fragmentation of the block structure as a result of cold deformation in the areas of maximum creep of the metal. At a lower degree of deformation it was possible to identify deformation of the blocks simultaneously with their angular disorientation. Greater angular disorientation which might be caused by the formation of twinned crystals was not observed. Both the cast and recrystallized materials show a zone of fragmentation on the grain boundaries.

The fact that there was good agreement between the dimensions of the block structure of pure aluminium as determined in this work and the results of X-ray investigation,[5] is evidence of the soundness of the study of these sub-lattice structures, which bear a direct relationship to the strength properties of the material.

References

(1) H. Fischer and L. Koch, *Metall*, 1952, **6** (17/18).
(2) I. Hrivnak, *Hutnické Listy*, 1958, **13** (6), 526.
(3) M. Hunter and F. Keller, Symposium on Techniques for Electron Metallography, ASTM Special Technical Publication, No. 155.
(4) G. Haas, *J. Optical Soc. of America*, 1949, **39** (7).
(5) J. S. Umanskii and L. Kh. Pivovarov, Zavod. Lab., 1958, No. 5.
(6) M. S. Hunter and D. L. Robinson, *J. Metals*, 1953, May, p. 717.
(7) N. C. Welsh, *J. Inst. Metals*, 1956, **85**, December, p. 129.
(8) J. S. Umanskii, Trudy vsesoyuznogo soveshchaniya, Mashgiz, 1949.

Spark machining symposium

Characteristics of spark erosion circuits

P. G. FARLEY, B.Sc., A.M.I.E.E.

This article is the first of a series on spark machining. It forms part of the symposium held recently at Birmingham by the NADFS *in collaboration with* METAL TREATMENT. *The remaining papers, together with the synopsis and discussion, will appear in this journal bi-monthly. Mr. Farley is senior lecturer in the Department of Electrical Engineering, College of Advanced Technology, Birmingham*

ALTHOUGH THE EROSION of metals by spark discharge was observed some 200 years ago, this technique was never used in a machining process until engineers of the 20th century were faced with particular problems, such as those of machining intensely hard materials; problems against which the more conventional machining processes were of little use. Much pioneer work was carried out during the war in Russia by the Lazarenkos[1] and the first British Patent was granted to Rudorff[2] in 1950. Since that time, the new technology of the electro-erosion of metals has developed at an amazing rate so that at the present moment machines of at least a dozen different manufacturers are now available in this country.

The number of basic electrical circuits used is far less even than this number and the purpose of this paper is to analyse the characteristics which the electrical circuity must invariably impose on the machine tool and to compare these for various systems as far as available information allows.

Basic principles

When an electrical discharge takes place between two electrodes, in general both surfaces will suffer erosion. When repeated discharges are made to take place in a dielectric medium, as in machining by electro-erosion, the nature of the resulting surface will be determined by the particular type of discharge as well as by the electrical parameters of the circuit.

The ' spark ' discharge is essentially transient in character involving a relatively high current flowing for a short period of time. Initially, electrons are extracted from the cathode by field emission and these are greatly increased in number by the ionization of the dielectric medium. The resulting ' electron avalanche ' constitutes the spark and so the greatest erosion occurs where these electrons impinge on the positive electrode (anode). Because of the short duration of the spark, the erosion resulting from any single discharge is highly localized.

The arc discharge differs from the spark in that it is essentially stable, electrons being produced by thermionic emission from a hot cathode. The conduction process is basically ionic and as such takes longer to establish. The currents involved are appreciably lower than for sparks and the greater erosion occurs at the negative electrode (cathode) surface due to melting. With prolonged arcing, however, the surfaces of both electrodes will be appreciably heated.

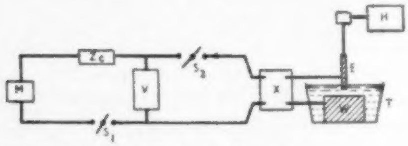
The distinction is, therefore, largely one of time. If the electrical circuit is so arranged that the discharge is over in about 10^{-4} sec., then a spark will result; but should the circuit permit current to flow in the discharge for appreciably longer periods, a more arc-like character will become apparent, increasing with increasing time.

There is a further practical distinction which becomes evident when machining by electro-erosion. Since spark discharges give a very localized effect, the size of each individual crater being determined by the energy per discharge, it is possible to produce very good surface finishes with no change in metallurgical condition of the surface or underlying metal. The arc discharge, exhibiting more sustained heating of the cathode surface, can give higher rates of metal removal but only at the expense of surface finish and, in some cases, changes in structure of the surface material.

This brief description of the discharge processes used in erosion machining (which have been dealt

with much more fully by Rudorff[3] and Ullmann[4] enables us to specify the basic components of a spark-erosion circuit. These we can draw in a generalized diagram as suggested by Bruma.[5]

In fig. 1 M is the source of electrical energy either alternating or direct. This charges an energy storage device V through a charging impedance Z_c (which



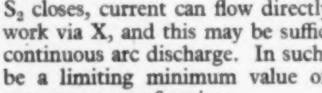
1 *General circuit for spark machining*

determines the rate of charging) and switch S_1 (which can be used to isolate M from the rest of the circuit if required). During the charging process, therefore, S_1 would be closed and S_2 open.

At some pre-determined instant in this charging cycle switch S_2 is closed and the energy then stored in V is transferred via the coupling element X (a transformer, for example) to the gap between work-piece W and cutting electrode E, both of which are immersed in the dielectric fluid contained in tank T. The relative time at which S_2 is closed determines therefore the relative energy in a single discharge. The frequency of operation of S_2 determines the rate at which successive discharges follow one another and so enables the power flowing into the work to be controlled.

The precise nature of the discharge will be determined primarily by the electrical constants of the discharge circuit (including X), but also by the components S_1 and Z_c; since if S_1 is not open when S_2 closes, current can flow directly from M to the work via X, and this may be sufficient to sustain a continuous arc discharge. In such cases, there will be a limiting minimum value of Z_c which will prevent an arc forming.

The last item in the general spark erosion circuit is the servo device H which advances the electrode towards the work so as to maintain a fixed gap



2 *Basic R—C relaxation circuit*

between them irrespective of the rate of metal erosion.

All spark erosion circuits must contain some of the items listed in the general circuit and it is the selection or omission of certain items that gives to a particular circuit its individual characteristics in operation. It is convenient to divide them into two main groups according as to whether the discharge is controlled solely by gap conditions (*i.e.* the breakdown of the gap itself replaces the action of S_2 in the general circuit) or is independent of them.

DEPENDENTLY-TIMED SYSTEMS

D.C. systems charging capacitance via resistance only

The basic circuit of this type is that used first by Lazarenkos and shown in fig. 2. When the switch is closed, the capacitor C begins to charge through the resistance R and so the voltage across C rises until it finally reaches the critical value at which the dielectric between electrode and work-piece breaks down. C then discharges very rapidly through the gap and the voltage across it falls so that eventually the dielectric de-ionizes and C is allowed to re-charge again, beginning another charge-discharge cycle.

Assuming that the discharge is instantaneous and complete, the wave-forms of voltage across the gap and current into the capacitor can be expressed thus:

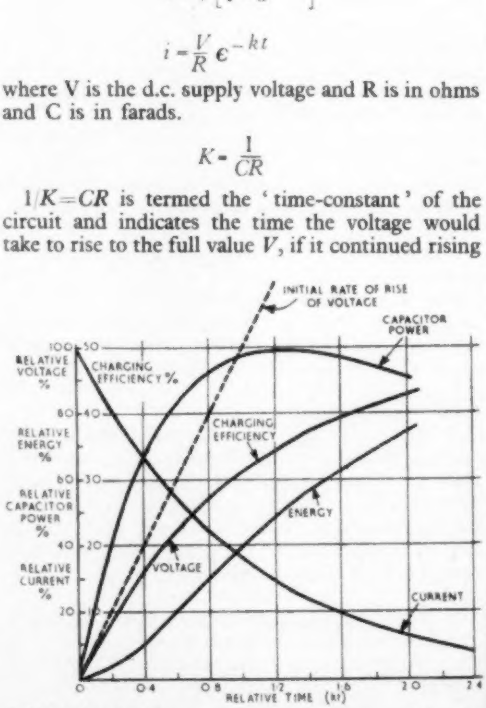
$$v = V\left[1 - \epsilon^{-kt}\right]$$

$$i = \frac{V}{R}\epsilon^{-kt}$$

where V is the d.c. supply voltage and R is in ohms and C is in farads.

$$K = \frac{1}{CR}$$

$1/K = CR$ is termed the 'time-constant' of the circuit and indicates the time the voltage would take to rise to the full value V, if it continued rising



3 *Variations in voltage, current, power, energy and charging efficiency with charging time in a simple R—C circuit*

at its initial rate. Using this idea we can plot the generalized voltage/time and current time curves as shown in fig. 3, where voltage is expressed as per cent. of the maximum attainable, *i.e.* V and time is expressed relative to the circuit time constant.

It can be shown quite simply that the energy stored in the capacitor after a time T is given by

$$\frac{1}{2}CV^2\left[1-\epsilon^{-kT}\right]^2$$

and up to this time the energy dissipated in the resistor

$$=\int_0^T i^2R\,dt=\frac{1}{2}CV^2\left[1-\epsilon^{-2kT}\right]$$

The charging efficiency, which is the ratio of the energy stored in the capacitance to the total energy supplied is therefore given by:

$$\eta_c=\frac{\frac{CV^2}{2}\left[1-\epsilon^{-kT}\right]^2}{\frac{CV^2}{2}\left[1-\epsilon^{-kT}\right]^2+\frac{CV^2}{2}\left[1-\epsilon^{-2kT}\right]}$$

$$=50\left[1-\epsilon^{-kT}\right]\%$$

and this has a maximum value of 50% when the capacitor is allowed an infinitely long time to charge. In practice the charging time must be restricted and the charging efficiencies obtained are much lower even than 50%. Suppose that the electrode gap is set to such a value that discharge occurs after a charging time T when the voltage has reached V_T. Then since

$$V_T=V\left[1-\epsilon^{-kT}\right]$$

it can be shown that:

$$T=CR\ \ln\left[\frac{V}{V-V_T}\right]$$

This is the time taken to charge the capacitor to voltage V_T and if the discharge is instantaneous the repetition frequency of successive discharges will be given by:

$$f=\frac{1}{CR\ \ln\left[\frac{V}{V-V_T}\right]}\quad \text{c/s}$$

The rate at which material is removed by electro-erosion depends not only on the repetition frequency but also upon the energy in each discharge, *i.e.* the machining rate depends on the rate at which energy is fed from the capacitor into the gap. From the expressions given above it can be seen that:

Average power supplied by capacitor to gap

$$\doteq\frac{1}{2}CV^2\left[1-\epsilon^{-kT}\right]^2\cdot\frac{1}{T}$$

$$=\frac{V^2}{2R}\cdot\frac{\left[1-\epsilon^{-kT}\right]^2}{kT}$$

By differentiation it can be shown[6] that a maximum in capacitor power occurs if charging is allowed to take place only until the voltage reaches about 71·5% of the maximum value. The power is then approximately[7] $V^2/5R$, the charging efficiency only 35·8% and the repetition frequency is given approximately by $0{\cdot}8/CR$ c./s. Graphs of resistance and frequency for various capacitor values have been given by Seed and Drubba.[6]

If the expression for repetition frequency is substituted into that for capacitor power we have

Average power=

$$P_c=\frac{V^2}{2R}\cdot\frac{\left[1-\epsilon^{-kT}\right]^2}{\ln\left[\frac{V}{V-V_T}\right]}$$

The above equations indicate that four parameters are available for controlling the operation of a spark erosion machine of this type, *viz.* supply voltage, charging resistance and capacitance together with the gap setting.

(a) *Supply voltage* All other things being equal, increase in supply voltage will increase the energy per spark and so increase the power available, but only at the expense of surface finish. The selection of the supply voltage is therefore in the nature of a compromise, since other factors such as the physical size of the equipment and danger of electric shock to operators must also be considered. Consequently supply voltage is usually fixed in design and not under the operator's control.

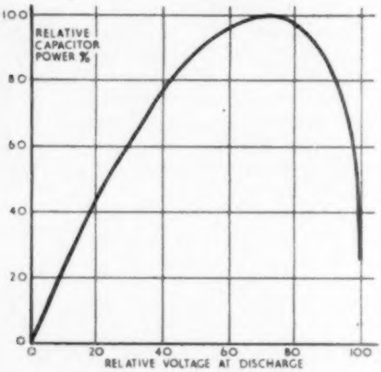
(b) *Charging resistance* With constant gap setting, the cutting power available varies inversely as the value of R (since with decrease in R we increase the frequency of sparking without altering the energy per spark) and this control is normally available to the operator. Power cannot, however, be increased by this method without limit, since there will be a certain minimum value of R below which there is the probability of continuous arcing with consequent deterioration in surface finish.

(c) *Capacitance* Increase in capacitance increases the energy per spark and at the same time reduces the spark frequency for a given gap setting. The cutting power available is, therefore, virtually unaltered and the surface finish deteriorates. This control is also normally available to the operator.

(d) *Gap setting* Fig. 4 shows how the cutting

power depends on the relative voltage to which the capacitor is charged (and at which the gap breaks down).

If the gap is larger than the optimum the consequent reduction in frequency is not compensated for by the increase in energy per spark and so the power falls. At shorter gaps the power falls again because the increased frequency is not sufficient to compensate for the reduced energy stored. In practice it becomes increasingly difficult to ensure



4 *Relationship between power and voltage at discharge for R—C circuit*

optimum conditions as power is increased because:

(a) The dielectric in the gap is increasingly fouled with metal particles and breakdown will occur at lower voltages.

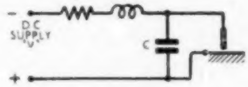
(b) With increasing power, R is reduced and so the initial rate of rise of voltage across the capacitor and gap ($= \dfrac{V}{CR}$ volts per sec.) is increased—this again tends to make the gap break down at a lower voltage.

This practical problem of gap de-ionization, therefore, limits the upper frequency of operation of the simple R—C circuit to about 10 kc./s. and so limits the power available for given surface finish. Further increase in power can only be obtained if the discharge is made independent of conditions in the gap, by an external switching device such as S_2 in fig. 1. This technique will be dealt with later.

To sum up, the R—C circuit is capable of producing fine surface finish; but in general the rates of stock removal and overall efficiency (measured in amount of metal removed per unit of energy consumed) are low. It is, however, economical in components and with a well designed servo system has been proved to be most reliable in operation over quite a number of years.

D.C. systems charging capacitance via resistance and inductance

Some at least of the disadvantages of the Lazarenko circuit can be overcome if an inductor is included in the charging circuit (as in fig. 5). The presence of inductance ensures that at the beginning



5 *Relaxation circuit with series inductance, L*

of the charging cycle the current is zero, so that the rate of change of the voltage across the capacitor and gap is also zero (as compared with $\dfrac{V}{CR}$ in the C—R circuit). This voltage, tending to re-form the discharge across the gap, is initially slow to rise and so more time is available for de-ionization of the dielectric and higher sparking frequencies are possible.

The precise wave-forms of the capacitor voltage and the charging current will depend on the relative values of C, L and R. Using the Laplace transform, we can express the capacitor voltage as v where

$$v(p) = \frac{V}{LC} \cdot \frac{1}{p} \cdot \frac{1}{p^2 + (R/L)\,p + (1/LC)}$$

and the precise solution to this will depend upon the quadratic term in the denominator.

(a) If $R^2 > \dfrac{4L}{C}$ the quadratic will have real and distinct roots so that we can write

$$v(p) = \frac{V}{LC} \cdot \frac{1}{p} \cdot \frac{1}{(p+\beta)(p+\gamma)} \qquad \gamma\beta = \frac{1}{LC}$$
$$\gamma + \beta = \frac{R}{L}$$

and the solution to this can be shown to be

$$v(t) = V\left[1 - \frac{1}{\gamma-\beta}\left\{\gamma\epsilon^{-\beta t} - \beta\epsilon^{-\gamma t}\right\}\right]$$

so that v only attains its maximum value of V after infinite time.

Similarly:

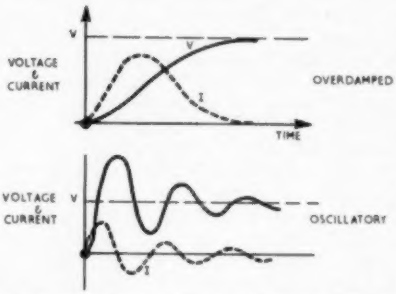
$$i(t) = \frac{V}{L} \cdot \frac{1}{\beta-\gamma}\left[\epsilon^{-\gamma t} - \epsilon^{-\beta t}\right]$$

Typical wave-forms of v and i are sketched in fig. 6 (*a*). In addition we can show that the charging efficiency (as defined earlier) if we stop charging after time T seconds is given by:

$$\eta c = \frac{50}{\beta-\gamma} \cdot \left[\beta(1-\epsilon^{-\gamma t}) - \gamma(1\ \epsilon^{-\beta t}\right) \%$$

i.e. Efficiency is at its maximum value of 50 only if a very long time is allowed for charging, in which case the power available would tend to zero as for the normal C—R circuit.

This brief analysis indicates that if the value of charging inductance is relatively low so that there is



6 *Typical current and voltage wave-forms in an R—L—C circuit: (a) overdamped, (b) oscillatory*

no oscillation of the series resonant circuit, there is little advantage gained over the simpler RC circuit except that the voltage tending to re-strike the arc is slower to rise after each discharge and so higher frequencies can be used.

(b) If $R^2 < \dfrac{4L}{C}$ the quadratic expression has imaginary roots and we have to re-write the original equation in the form

$$v(p) = \frac{V}{LC} \cdot \frac{1}{p} \quad \frac{1}{(p+a)^2 + \omega^2}$$

where

$$a = \frac{R}{2L} \ \& \ \omega^2 = \left[\frac{1}{LC} - \frac{R^2}{4L^2}.\right]$$

The solution of this can be shown to be:

$$v(t) = v\left[1 - \epsilon^{-at}\left\{\cos.\omega t + \frac{a}{\omega}\sin.\omega t\right\}\right]$$

and in a very similar way

$$i(t) = \frac{V}{\omega L} \cdot \epsilon^{-at} \sin.\omega t$$

These wave-forms are sketched in fig. 6 (*b*) showing the characteristic form of sine waves of frequency $f = \dfrac{\omega}{2\pi}$ the amplitudes of successive waves decreasing exponentially because of the ϵ^{-at} term (representing the dissipation of energy in the resistive part of the circuit).

It can be seen that most of the energy stored in the inductor in the first quarter-cycle is passed to the capacitor in the second quarter-cycle, causing its voltage to swing to a value in excess of the supply voltage. This first voltage maximum is achieved in a time which depends on the frequency of oscillation of the series circuit and can be made very short by reducing both L and/or C and making $\dfrac{R^2}{4L^2}$ small compared with $\dfrac{1}{LC}$. From the point of view of spark machining we require to store energy as quickly as possible so we need consider only the first half-cycle and it would seem worth while to deduce from the appropriate equations the conditions for maximum power transfer to the work and the expressions for charging efficiency, comparable with those for the C—R circuit. If the capacitor be allowed to charge for a time T, is then instantaneously discharged to begin recharging again, the average power flowing from the capacitor is given by:

$$P_c = \frac{CV^2}{2T}\left[1 - \epsilon^{-aT}\left\{\cos.\omega T + \frac{a}{\omega}\sin.\omega T\right\}.\right]^2$$

The determination of the maxima and minima of this function would be a laborious process and it is felt that for the purpose of this paper, sufficient information can be obtained by considering only the particular case of $\alpha = 0$ (corresponding to a circuit with negligibly small resistance).

Here we have

$$v = V\left[1 - \cos\omega_0 t\right] \qquad \omega_0^2 = \frac{1}{LC}$$

so that the average power

$$P_c = \frac{\omega_0 CV^2}{2} \frac{\left[1 - \cos\omega_0 t\right]^2}{\omega_0 t}$$

and differentiation of this yields an equation of the form:

$$\left[1 - \cos\omega_0 t\right]\left[\cos\omega_0 t + 2\omega_0 t \sin\omega_0 t - 1\right] = O$$

Graphical solution of this shows that the first maximum in power occurs at $\omega_0 t = 159°$, *i.e.* when the voltage is 1·934V and the stored energy is 93·5% of its maximum value. The maximum power can then be shown to be:

$$\hat{P}_c \doteq \frac{2{\cdot}11}{\pi} V^2\sqrt{\frac{C}{L}}$$

which is only some 5% greater than the value

$$\frac{2V^2}{\pi}\sqrt{\frac{C}{L}}$$

which would have been obtained had we allowed the capacitor to charge to its maximum voltage of 2V

For the purposes of simplifying subsequent analysis therefore, it would not seem unreasonable to assume that the capacitor is charged every time to its first maximum value and then discharged, these conditions being not far removed from the maximum power conditions.

Applying this to the general expression for the circuit of fig. 5, we have

$$v_{\max} = V\left[1+\epsilon^{-\frac{\alpha\pi}{\omega}}\right]$$

after half a cycle.

Energy stored at this time on the capacitor

$$W_c = \frac{1}{2}CV^2\left[1+\epsilon^{-\frac{\alpha\pi}{\omega}}\right]^2$$

but the total energy supplied can be shown to be

$$W_T = CV^2\left[1+\epsilon^{-\frac{\alpha\pi}{\omega}}\right]$$

Hence the charging efficiency is given by

$$\eta_c = 50\left[1+\epsilon^{-\frac{\alpha\pi}{\omega}}\right]\ \%$$

Similarly it can be shown that capacitor power

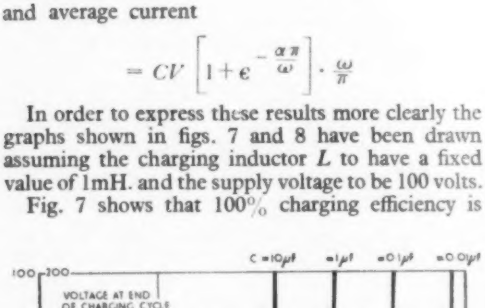
$$= \frac{CV^2}{2}\cdot\left[1+\epsilon^{-\frac{\alpha\pi}{\omega}}\right]^2\cdot\frac{\omega}{\pi}$$

and average current

$$= CV\left[1+\epsilon^{-\frac{\alpha\pi}{\omega}}\right]\cdot\frac{\omega}{\pi}$$

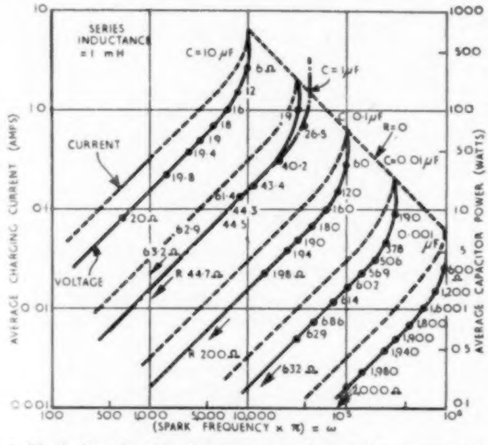
In order to express these results more clearly the graphs shown in figs. 7 and 8 have been drawn assuming the charging inductor L to have a fixed value of 1mH. and the supply voltage to be 100 volts.

Fig. 7 shows that 100% charging efficiency is



7 *Charging efficiency and voltage against frequency for R—L—C circuit*

obtainable only when $R = 0$ (*i.e.* $\alpha = 0$) and that as R is increased, the efficiency falls very rapidly to the region of 50%. It can also be seen that at zero resistance the capacitor voltage rises to a maximum value of twice that of the supply but as R is increased, it falls rapidly to equal the supply value.



8 *Variations for charging current and capacitor power with frequency in R—L—C circuit*

Fig. 8 shows that as we increase towards the critical value that would stop oscillation

$$\left[\frac{R^2}{4L^2} = \frac{1}{LC} \qquad \text{i.e.} \qquad R = 2\sqrt{\frac{L}{C}}\cdot\right]$$

the cutting power available from the capacitor and the average charging current both fall off proportionally with the oscillation frequency. Over this linear range the system is only just oscillating and the capacitor voltage is very little more than that of the supply, so that the energy for discharge is sensibly constant and we vary power by varying the time taken to charge.

At relatively small values of R, the circuit oscillates much more freely and power increases rapidly because there is considerably more energy in each discharge.

Fig. 8 also shows that with a 10 µF capacitor, the series resistor need only be varied over 0 to 20 ohms to cover the whole power range; but when a much lower capacitor of 0·001 µF is used (for fine surface finish) a resistance range of 0—2,000Ω is required. The resistor, which is usually a multipoint rheostat, would therefore need to be carefully graded to give as wide a power variation as possible in reasonably equal increments whatever value of capacitor is in use.

The additional curve on fig. 8 shows the effect of

halving the value of the charging inductor. The lower left hand portion of the curve is unaltered in that the same power is produced at the same frequency, but the resistor value required to produce this is reduced. At the other end of the curve, where the circuit is oscillating more freely the effect is to give reduced power at any given frequency, but at the same time to extend both the power and frequency range.

Summarizing, the main advantages that accrue from the use of series inductance are:

(*a*) Restriking voltage rises at a much slower rate so that higher frequencies are theoretically possible.

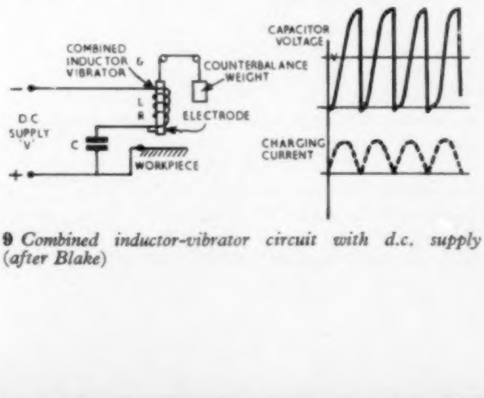
(*b*) If the inductance is such that the series circuit is oscillatory, further increases in power and charging efficiency are possible.

These advantages have been shown to occur in practice by various Russian writers[8] who quote increases in machining efficiency of 25—30% and by Williams, Woodford and Smith who give an increase in machining speed of perhaps four times that of the basic *C—R* circuit. Comparisons of this type can, however, be misleading unless the fullest information about the particular machining operation is also available. Increased power available from the electrical circuit, however, often cannot be fully realized as increase in machining speed because the charge-discharge cycle is still dependent on conditions in the gap, and increased stock removal makes the gap more liable to premature breakdown because of the difficulty of removing the metal particles.

A.C. systems

In the systems already described, it has been necessary to provide a d.c. supply; this normally entails use of an input transformer and rectifier, the particular system employed depending on the nature of the alternating supply available.

If these items could be dispensed with, the initial cost and size of the equipment would be reduced; but such a system would have other disadvantages. If during the first half-cycle the work were made positive with respect to the electrode, then greater erosion by sparking would occur



9 *Combined inductor-vibrator circuit with d.c. supply (after Blake)*

at the work-piece. During the next half-cycle, the electrode would be the anode and in general there would be greater wear there than at the work-piece.

Unless, therefore, we can include some means of ensuring that the discharge occurs only when the work-piece is the anode, systems operating on a.c. must show much higher tool wear than d.c. systems. This is a serious practical disadvantage.

INDEPENDENTLY-TIMED SYSTEMS

Systems with vibrating electrodes

If the electrode is made to vibrate so that the gap between it and the work-piece opens and closes regularly the discharge is no longer entirely dependent on gap conditions. Sparking will be bound to occur while the electrodes are closest together and there will also be a time when the gap is too large for sparkover, *i.e.* a time when de-ionization of the dielectric is facilitated; voltage wave-forms of such a system have been given by Ullmann.[4] With a d.c. operated *R—C* system this seems to have little to commend it from the electrical point of view. Many of the discharges will be at a voltage considerably below the maximum and the cutting power will be still further reduced because of the relatively long inactive period at gaps too large for sparkover. It seems probable that the greatest advantage of this system is that the mechanical movement of the electrode assists materially in clearing metal particles from the gap.

A vibrating electrode can, however, be used to great effect when it is synchronized with the resonant frequency of a system charging capacitance via inductance from d.c. or a.c. as has been shown by Blake.[7]

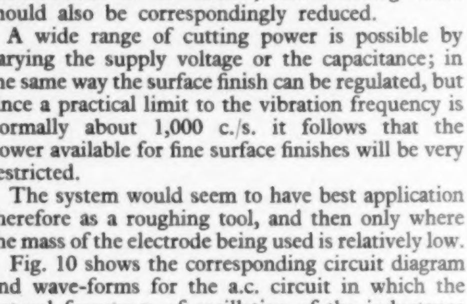
Fig. 9 shows the circuit diagram and wave-forms obtained with the d.c. system, from which it will be seen that this is basically of the type already described. Because of the low circuit resistance (only that of the inductor windings) the system operates very near to its natural resonance and the capacitor voltage is virtually twice that of the supply with corresponding increase in power and charging efficiency. The inductor core and the vibrator are combined, the natural frequency of vibration of the mechanical system (armature, restraining spring and cutting tool) being sufficiently high compared with the resonant frequency of the circuit that the desired movement of the electrode is obtained. No servo drive is necessary, automatic action being obtained by partially counterbalancing the head and allowing it to fall under gravity. The mechanical forces when electrode and work-piece meet are not large and this unavoidable contact does not seriously affect the charging efficiency since it takes place when the charging current is low and energy is mainly being stored in the inductor.

Charging efficiencies of the order of 95% are claimed for this type of machine. This means that since little energy is dissipated in series resistance the supply transformer and rectifier can be appreciably smaller for a given cutting power than in a conventional *C—R* circuit; the running costs should also be correspondingly reduced.

A wide range of cutting power is possible by varying the supply voltage or the capacitance; in the same way the surface finish can be regulated, but since a practical limit to the vibration frequency is normally about 1,000 c./s. it follows that the power available for fine surface finishes will be very restricted.

The system would seem to have best application therefore as a roughing tool, and then only where the mass of the electrode being used is relatively low.

Fig. 10 shows the corresponding circuit diagram and wave-forms for the a.c. circuit in which the natural frequency of oscillation of the inductance



10 *Combined inductor-vibrator circuit with a.c. supply (after Blake)*

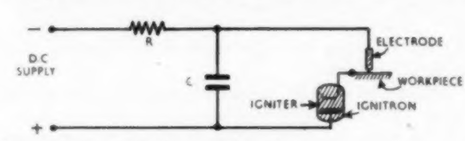
and capacitance is made equal to the supply frequency. Vibration of the tool is arranged so that the capacitor is always discharged at its second voltage maximum.

Since the normal supply frequency of 50—60 c./s. is too low for reasonable operation of a spark erosion machine, a high frequency alternator would be required to provide a supply of at least several hundred cycles per second, and this would add considerably to the cost. But a.c. operation does allow the possibility of using a matching transformer between capacitor and work; this would enable a high voltage low capacity capacitor to be used with consequent increase in spark repetition rate, whilst still maintaining optimum conditions in the gap.

Such a circuit again would find best application as a roughing tool.

Ignitron controlled systems

These can be basically of the *R—C* or *R—L—C* types, the only difference being that the discharge process is initiated by a suitable ' electronic switch ' instead of being dependent on the conditions within the gap. Limitations to present circuits are mainly concerned with the availability of suitable valves. For this type of work, the only suitable device at present available is the ' Ignitron,' which is a triode with a mercury pool cathode capable of carrying currents of several hundred amperes with a comparatively low volt drop. Conduction is



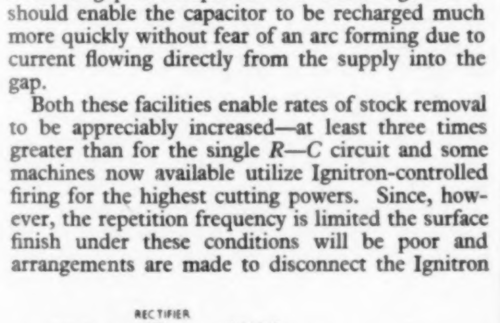
11 *Ignitron-controlled R—C circuit*

initiated by applying power to an igniter electrode which dips in the cathode pool, but thereafter the discharge maintains itself until the potential between anode and cathode of the valve falls below a certain minimum value. The way in which an Ignitron could be used as a switch in conjunction with an *R—C* circuit is shown in fig. 11.

The initiation of the spark discharge is governed by the wave-form applied to the Ignitron grid and so can be easily arranged to take place at any time during the charging cycle. After completion of the discharge, however, the Ignitron switch needs a certain time to ' open ' because of the finite time required to de-ionize the mercury vapour and this sets a practical limit to the number of switching operations (and hence spark discharges) that can be effected per second. At the moment this appears to be of the order 150—300/sec.[9]

In addition to giving reliability of spark initiation, this circuit also effectively isolates the capacitor from the gap on completion of the discharge and so should enable the capacitor to be recharged much more quickly without fear of an arc forming due to current flowing directly from the supply into the gap.

Both these facilities enable rates of stock removal to be appreciably increased—at least three times greater than for the single *R—C* circuit and some machines now available utilize Ignitron-controlled firing for the highest cutting powers. Since, however, the repetition frequency is limited the surface finish under these conditions will be poor and arrangements are made to disconnect the Ignitron



12 *Simplified diagram of pulse-forming circuit (after Williams and Porterfield)*

and use a simple R—C arrangement for lower power finishing work.

Further application of this type of controlled discharge must await the development of faster operating valves or suitable high power transistors.

Pulse-forming circuits

Attempts have been made to generate discharges at higher repetition rates by the use of more involved circuity of the type used in radar work. Systems of this type giving pulses of 0·2 to 50 microseconds length at repetition frequencies up to 20,000 per second and an average power up to 15 kW. have been described by Williams and Woodford[10] and Williams and Porterfield.[11]

Fig. 12 is a simplified version of the circuit used. The capacitor is charged from the 4,500 volt direct supply via the 872 rectifier and the transformer primary. When the rotary switch closes the capacitor discharges via the pulse transformer into the gap. To achieve high repetition rates, four such capacitors were actually used, being discharged sequentially by a special switch rotating at 3,600 r.p.m.

Basically, therefore, the system uses a low value of capacitance allowing a high repetition rate (since it can be discharged quickly) and very high charging voltage (to ensure a reasonable energy per discharge). Since spark erosion requires in general a low voltage, heavy current pulse, a transformer must be interposed between the pulse forming system and the work.

This novel approach has, however, some serious practical difficulties. The capacitor discharges into a circuit containing appreciable inductance; initially the primary magnetizing inductance of the transformer, but later, when sparking occurs, the reflected secondary inductance as well. This makes the discharge oscillatory, the precise wave-forms depending on how fast energy is being dissipated in the gap. If for some reason the dielectric between tool and work-piece fails to break down, all the capacitor energy is first transferred to the primary inductance of the transformer and then returned to the capacitor as a charge of opposite polarity. So the initial 'forward' pulse tends to be followed then by a second pulse of 'reversed' polarity which will, of course, give rise to undue electrode wear.

To overcome this difficulty it is necessary to include a bank of damping diodes (only one of which is shown in fig. 12) across the transformer primary to absorb the pulse energy when the work gap fails to spark over. Since the resistors R in this system must be capable of dissipating about 50% of the total power of the machine, the cost and size of the machine as a whole are greatly increased. In addition to this, the pulse transformer itself and the rotary spark-gap switch both present unusual problems in design and do not, at first sight, appear to be conducive to trouble-free operation over long periods with a minimum of servicing.

Summarizing, although such a system using independently controlled fixed amplitude discharges can provide a high degree of reproducibility and more reliable surface finishes even at high power, it will invariably be more costly in design and manufacture than relaxation machines giving comparable machining performance, and seems likely to require more servicing.

Special rotary generators for spark erosion

All the circuits so far discussed have employed true spark discharge techniques where the duration of the discharge has been short (about 10^{-4} sec.). It is probable that Russian investigators were the first to realize that much higher rates of stock removal were possible with the circuits arranged to allow a short controlled period of arcing following the initial sparkover, the total pulse length being 10^{-3} to 10^{-2} sec.

The general requirements of an electrical circuit for this type of work may be summarized as follows:

(*a*) To reduce electrode wear, the wave-form should be unidirectional.

(*b*) The voltages need not be high—no more than 100 V.

(*c*) Currents of several hundred amps peak must be supplied.

(*d*) Operation should be virtually independent of conditions in the work gap.

(*e*) Pulse repetition frequency should, if possible, be in the audio-range.

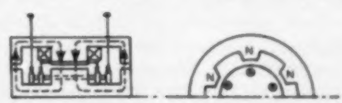
(*f*) Sufficient time should be allowed between pulses to enable the work gap to de-ionize fully.

Livshits and Rogachev[12] have described numerous approaches made in the U.S.S.R. to this problem of producing heavy unidirectional currents at low voltages and audio-frequencies. The most attractive solution from many points of view seems to be the use of specially designed rotary generators, which are of two types:

(*a*) Homopolar types in which the e.m.f. produced is pulsating but unidirectional, and

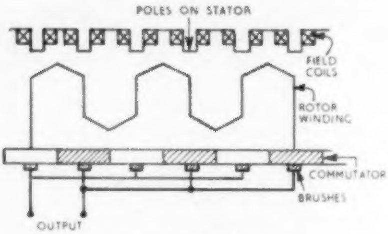
(*b*) Commutator types in which the e.m.f. produced is alternating and is subsequently rectified.

Fig. 13 shows diagrammatically the homopolar generator, which differs from conventional machines of this type because it has an airgap varying periodically round the armature due to the provision of



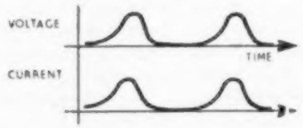
13 *Diagram of homopolar-type impulse generator (after Livshits and Rogachev)*

teeth on the stator. Each bar of the armature winding is connected to two sliprings, the outputs from all the bars being connected in series. A machine of this kind developed at the Kharkov Polytechnical Institute gave an average current of 150 amps at 15—20 volts and 800 pulses per sec. Fig. 14 (*a*) shows diagrammatically the commutator



14 (*a*) *Commutator-type rotary impulse generator (after Livshits and Rogachev)*

type of generator which is basically the same as a normal d.c. generator, but differs in many details. The pole arc is much smaller than normal (less than 50% of pole pitch) and the winding on the armature is grouped under the poles in narrow segments, these two factors combining to give a markedly pulsating e.m.f. The commutator has only as many bars as there are poles, alternate bars being linked together to form two systems insulated from one another. Two systems of brushes are provided disposed and connected as shown in the diagram. Typical resulting wave-forms of voltage and current are as shown in fig. 14 (*b*).



14 (*b*) *Typical waveforms of commutator-type rotary impulse generator*

Further information on machines of this type has been given by Nicolas[13] and one manufacturer in this country is now building such a generator. This has 8 poles and being driven at 3,000 r.p.m. gives 400 pulses per sec. of up to 200 amps at 70—80 volts.

Because the discharge mechanism is part-arc such machines could not be used for work requiring fine surface finish, but the very high rates of stock removal (in some cases up to 10 times that by normal *R—C* circuits) make it most attractive for roughing work. In several cases machines have been built incorporating a rotary impulse generator of the commutator type for roughing (where the current is controlled by simple series resistance) and a convenient spark arrangement for finishing. The same servo-system gives automatic feeding of the electrode in both cases.

The discharge process

In the previous section the importance of unidirectional voltage between electrode and work was stressed if tool wear is to be kept to a minimium. In rotary impulse generators and other ' independent ' systems, special precautions are taken to ensure this.

In dependent-timed systems, however, the wave-form of the discharge is determined by the electrical constants of the discharge circuit. Assuming that this, in its simplest form, consists of the circuit shown in fig. 15 we see that the discharge current will be oscillatory if $(R + R_g)^2$ is less than $\frac{4L}{C}$ but non-oscillatory if it is greater than this value.

In order to lose as little of the stored energy as possible in transit, the lead resistance *R* should be as low as possible, and in order for the discharge to be over as soon as possible the circuit must not be too heavily damped. If, however, the discharge oscillates too freely there will be an appreciable time when the polarities of work and electrode are reversed and tool wear will increase.

Under oscillatory conditions the discharge current is given by the expression

$$i(t) = \frac{V}{\omega L} \cdot \epsilon^{-\alpha t} \sin \omega t \qquad \alpha = \frac{(R+R_g)^2}{2L}$$

$$\omega^2 = \left[\frac{1}{LC} - \frac{(R+R_g)^2}{4L^2}\right]$$

so that the inductance of the leads has great effect on the magnitude of the discharge current.

Attempts have been made[10] to minimize inductance and so increase peak discharge currents both by using a true coaxial assembly, or an approach to this with a basket-like network of leads which give better access to the work than the solid sheath of a coaxial enclosure.

The problem of reducing the inductance and lead resistance in the discharge path cannot, however, be divorced from the general problem of the mechanical design of the machine tool and any practical solution must be a compromise depending on the nature of the work to be done.

15 *Simplified discharge circuit*

Conclusions

Spark erosion is a process in which metal is removed by electrical discharges and the greater the energy per discharge, the greater the amount of metal removed. It is therefore axiomatical that increase in stock removal rate can only be obtained at the expense of surface finish, unless there are corresponding increases in the frequency of sparking.

The earliest relaxation circuit devised is still in widespread use today because of its proved reliability and capability of providing fine surface finish. Since stock removal rates were, however, so very much lower than with conventional machine tools the development of subsequent circuits outlined in this paper has been towards increasing the machining rate either by increasing the electrical energy available, increasing the spark frequency or making the operation of the machine less dependent on gap conditions. The latest circuits have attained such high machining rates that this process becomes far more attractive for machining large workpieces, but the original relaxation circuits must still be used for finishing operations.

From information now available it appears that present-day electrical circuits are capable of delivering rather more power into the work-gap than the production engineer can conveniently use. Immediate future developments must, therefore, be in application techniques rather than in devising new electrical circuits. But it is equally certain that new circuit techniques will subsequently be developed to meet the widening demand for this most versatile machine tool.

Acknowledgments

The author wishes to thank many colleagues of the College of Advanced Technology, Birmingham, for help and encouragement and the many manufacturers of spark erosion equipment who have so helpfully co-operated in providing information.

References

(1) B. R. Lazarenko and N. I. Lazarenko, *Stahki I. Instrument* (*U.S.S.R.*), 1946, **17**, (12), 8, and 1947, **18**, (2), 4. Also Swiss Patent 257,484, April 1, 1949.
(2) D. W. Rudorff, Brit. Patent No. 637,872, 1950.
(3) D. W. Rudorff, *Proc. I. Mech. E.*, 1957, **171**, (14), 495.
(4) W. Ullmann, *Technische Rundschau*, Berne, Switzerland, February 28, 1958, No. 8.
(5) M. Bruma, '*Schweizer Archiv fur angewandte*,' *Wissenschaft und Technik*, January, 1956, **22**, P. 1, 18.
(6) M. G. Seed and H. Drubba, *Engineers' Digest*, September, 1954, **15**, (9), 378.
(7) L. R. Blake, *The Engineer*, February 18, 1955.
(8) A. V. Nosov and D. V. Bykov, 'Working Metals by Electro-sparking,' D.R.I.R. Translation, published by H.M.S.O. 1956, p. 27.
(9) D. W. Rudorff, Paper 50 at Conference on Technology of Engineering Manufacture organized by the Institution of Mechanical Engineers in London, March 25-27, 1958.
(10) E. M. Williams and J. B. Woodford, Transactions I.R.E. Professional Groups C, P.G.I.E.—2, March, 1955, p. 78.
(11) E. M. Williams and C. P. Porterfield, *Electronics*, October 24, 1957, p. 90.
(12) A. L. Livshits and I. S. Rogachev, *Elektrichestvo No.* 3, 1957, p. 19.
(13) T. Nicolas, *La Machine Moderne*, May, 1957, No. 578, p. 73.

AUTHOR'S SYNOPSIS

Mr. P. G. Farley said that before he reported on his lecture a few words about the background of the lecture might not be inappropriate. He was by training and by inclination an electrical engineer, and his presence at the meeting was occasioned by a need for a paper which would integrate together as a whole an analysis of the many different circuits at present available for spark and spark arc machining. It might seem rather strange, as Mr. Swain had pointed out the previous evening, that he should attempt to write an integrating paper on methods of electrical disintegration, but that was his object in writing the paper. It was unfortunate that it brought in its train a certain amount of mathematics. He assured his audience that he did not wish to bother them with mathematics at that early hour. He would attempt to read between the mathematical lines and point out what he considered to be the main features of his paper.

The technique of spark machining was of particular interest to most electrical engineers, because it was one of the few direct applications of purely electrical phenomena to the removal of metal. As such there was a very close linkage between the circuit designer and the production engineer which it would be hard to find in any other sort of technology.

Sparks and arcs

From the point of view of metal removal, electrical discharges could be divided into two broad types—the spark and the arc. The main distinction was purely one of time. The spark was a transient phenomena; it was a sudden short release of energy, and therefore its effects upon the metal surface were very localized. However, if a spark was allowed to persist for too long it would transform itself into an arc. An arc was a self-supporting device whose effects upon the metal surface were much more widespread and much deeper.

It was not surprising, therefore, that the earliest applications of this sort of technique to accurate machining were concentrated almost entirely on the use of spark discharges. This necessarily required a certain type of circuit in which energy could be first accumulated in some kind of reservoir and then released quickly in the form of a spark. This process, for continuous machining, must be repeated at frequent intervals.

Relaxation circuits

The earliest and still the most widely used circuit of this type was the so-called 'Relaxation Circuit' or resistance capacity circuit due to the Russians Lazarenkos and shown in fig. 2 of the paper. Energy was accumulated electrostatically in a

capacitor *via* a resistance. This went on until the capacitor voltage had risen to such a value that the oil or dielectric between the electrode and the work-piece broke down. At this point the stored energy was released and, because of the low resistance and inductance of the discharge path, this release of energy was accomplished in a very short space of time and a spark took place between the electrode and work-piece. When the voltage across the capacitor had fallen to a sufficiently low value, the oil healed over, the dielectric strength was re-established and the capacitor began to recharge, thus starting another cycle of operations.

This circuit, which was the simplest circuit, highlighted some fundamental points about spark machining. It should always be remembered that, though it was the energy contained in a single discharge which determined the size of the crater formed in the work-piece and so fixed the surface finish of the material, the rate at which metal was removed depended not only upon this, but upon the speed at which such discharges followed one another.

Basically, there were two methods of control of this type of circuit. The energy per discharge could be varied, or the frequency at which such discharges follow one another could be varied.

In a practical circuit there were three or four different variables. The voltage to which the capacitor was charged was normally fixed in design and not at the discretion of the operator. He had shown in the paper, as was well known, that there was a definite setting of the gap between the work-piece and the electrode, which would correspond to the maximum transfer of power from the electrical circuit into the gap. If the gap was fixed, by and large the setting of the capacitor controlled the surface finish. The setting of the resistor, by altering the frequency of discharge, controlled the flow of power from the circuit into the gap.

This circuit had many advantages of simplicity, but some attendant disadvantages. First, the maximum operating frequency was limited to the order of 10,000 c./s. because of the limited time available for the healing over of the oil dielectric. This was not helped at all by the circuit characteristic of rapid rate of rise of voltage across the gap after the capacitor had been discharged. This rate of rise of voltage across the gap, which was the characteristic which determined when the gap would break down again, increased with increased power and so made for greater difficulty at higher powers.

The second point, which was particularly interesting to him as an electrical engineer, was that from the point of view of the transference of energy this circuit was relatively inefficient. He had shown that the charging efficiency, that is to say the ratio of the amount of energy stored in the capacitor to the total amount of energy fed into the circuit during the charging cycle, could never be higher than 50% and at the condition of maximum power transfer was round about 35%. From the point of view of the circuit designer this meant that the series resistance must be capable of dissipating continuously approximately twice the power that was active in the gap, and the main supply transformer and rectifiers must be capable of handling roughly three times this power.

Some at least of these disadvantages could be overcome by using series inductance in the circuit, as shown in fig. 5. The circuit characteristic in this case was that the voltage present across the gap after the completion of discharge was much slower to rise because of the presence of some electrical inertia in the circuit when the inductor was connected. Because the voltage across the gap was much slower to rise, there was much more time available for de-ionization or healing over of the oil, and frequencies as high as 1 Mc./s. were practicable. Again from the circuit point of view, still further advantages could be obtained if the components' values were selected so that the circuit could oscillate. In these cases it was possible for a capacitor voltage to swing to a value almost twice the supply voltage, giving a four-fold increase in energy per discharge. The charging efficiency was never less than 50% and could be much higher than that.

The systems so far described depended on a breakdown of the dielectric to initiate the spark and de-ionization or healing over of the dielectric to stop it. At higher working powers the gap must of necessity be increasingly fouled with metal particles and would tend to break down at lower and lower voltages. So the theoretical ideas of power transfer could rarely be fully achieved in practice. This disadvantage had led to the development of further circuits in which the control of the instant of capacitor discharge and of recharging were removed from the gap and carried out by some external mechanism.

Vibrating electrodes

One way of ensuring regularity of discharge was to vibrate the electrode, but from the electrical point of view this seemed to have little to commend it in the simplest type of resistance capacity system. If, however, the vibration frequency was also the resonant frequency of a series resistance inductance circuit, quite high rates of stock removal were possible, as had been shown by Blake in a paper in *The Engineer*. But the attendant practical problem of vibrating other than the smallest electrodes at suitable frequencies up to 1,000 c./s. seemed to make these systems of limited use in production.

The release of stored energy in the capacitor could be effected also by some form of valve. The so-called 'hard' valves or high vacuum valves suffered from the basic disadvantage that they were essentially high voltage/low current devices, whereas spark erosion in general required a heavy current pulse at a relatively low voltage. The necessary auxiliary circuity could, therefore, become very complicated. He had simplified one such diagram in fig. 12. This increased appreciably the initial cost of the apparatus and also the problems of maintenance and servicing.

Of the so-called 'soft' valves, only the Ignitron was at present capable of handling the currents required for spark erosion. Here the spark frequency was at present restricted by currently available types to the order of 150 to 300 c./s. It was, nevertheless, in use at present and future developments, both with that type of valve and with high power transistors, would certainly increase the range of application of this circuit.

Low frequency 'roughing'

All the circuits mentioned so far had been of the type where energy was stored in a capacitor and released by the action of a switch of one sort or another, whether internally in the gap or externally as, for example, in the case of the Ignitron. Effective switch operation at high powers could at present be ensured only at low frequencies, and this of necessity meant a poor surface finish. There must be a high energy per discharge if the discharge rate was low for a high power, but this need be no disadvantage if it was realized that these circuits could be used for high-power roughing work, followed, for example, by the simple resistance capacity circuit for finishing. This was a technique which was already widely used in conventional machining, where separate machines were often used for roughing and finishing work. It seemed that the newer technology of spark erosion had now also reached that stage. Equipments were available commercially which used low-frequency Ignitron controlled firing for roughing work and a conventional resistance capacity system for finishing.

That idea of the division of labour between different types of circuit had been taken still further. Machines were now available which carried out the roughing process using a different type of basic discharge. This was a discharge which was allowed to carry on for a longer period and so consisted not only of a spark, but a subsequent arc. The electrical energy in these cases was no longer stored in a capacitor from which it had to be released by the operation of a switch. The necessary pulses of voltage were generated as required by a rather unusual type of rotating d.c. generator and so the voltage pulses were relatively independent of conditions in the gap. Such systems were capable of very high rates of stock removal and from the circuit point of view had all the advantages of simplicity. Control of the operation was very simply carried out by variation of a resistor in series.

It seemed that the stage had been reached when a wide range of equipments was available to cover virtually all the present needs of industry. In general, more electrical power could be delivered from the circuit into the gap than could conveniently be used by the production engineer. Immediate future development would therefore be in the realm of techniques of application, but it was equally certain that new circuit techniques would subsequently be developed to meet the widening demand for this very versatile tool.

DISCUSSION

Mr. R. T. Rentoul (Deritend Drop Forgings Ltd.) stated that, although no doubt Mr. Farley's paper was very interesting to some of those present, many drop forgers would find the technicalities a little hard to digest.

It would appear that for use primarily in die sinking at least two types of machines were required if the whole of the sinking of the impression was to be carried out by spark erosion. A homopolar machine was required for roughing out, followed by the normal capacitor machine for the finer finish. What were the relative costs of a homopolar machine and a copying machine of the conventional milling machine type? This was an important point needing clarification.

As regards the machines, the principal troubles he envisaged were the setting of the electrode on the job and the manufacture of the electrode. Did the composition of the electrode affect the characteristics of the circuit?

Mr. Farley, replying, said that the first question asked by Mr. Rentoul was a little out of his field as an electrical engineer. He was not in any way concerned with production problems in spark erosion. However, he was sure that some later lecturer, much more qualified to answer the question than he, would do so without the slightest hesitation.

Replying to the second question, Mr. Farley stated that from the electrical circuit point of view there seemed to be little effect of the electrode material on the operation of the circuit, particularly in the later circuits he had mentioned. However, in all these cases the electrical circuit could not be divorced from the end which it was desired to produce. There was a paper by Mr. Adcock entitled 'Electrode Materials.' He was sure that Mr. Adcock would bring out points which were much more interesting to production engineers on

the effects of the electrode material on the end it was designed to produce.

From the circuit point of view, all that could be said about the electrode material was that, in addition to a charging circuit, there was a discharge circuit. As he had pointed out in the paper, the electrical constance of the discharge circuit could have quite an effect upon the nature of the discharge, but the chief parameter of the discharge circuit which affected this was the inductance. It was normal to try to keep the inductance and the resistance as low as possible. The only effect he could see from the circuit point of view was that, if the electrode material was of extremely high resistance, which was not likely to be used in practice, the discharge circuit would be in such a condition of damping that the discharge would be unduly prolonged and there might be a change from a spark to an arc. The real answer to the problem could be given more accurately by a production engineer than by an electrical engineer. He was sure that the answer would be given by Mr. Adcock.

Mr. R. ING (Mallory Metallurgical Products Ltd.) asked whether there was any relationship between the cross-section area of the working part of the electrode and the power delivered for a given depth of dielectric.

Mr. Farley said that he took this to mean the power which could be delivered in practice to the electrode. This was a problem on which he—and he was in good company on this—would hesitate to express a generalized opinion. His audience, having read his paper, would realize that he had been rather careful to avoid quoting down-to-earth figures of stock removal rates for any given process. He had been afraid to do so, because he might have drawn some invidious distinctions between the various processes.

Any comparison, indeed any single figure, for stock removal rate could not be considered as worth anything at all unless the conditions under which it had been obtained had been very carefully laid down beforehand. Very often one read in the technical literature articles by people saying quite blithely that they could remove so many thousand cubic millimetres per second, per minute or per hour, but they gave very little information about the actual area and depth of the impression.

This was complicated in practice by the fact that difficulty had always been experienced in removing the waste products of erosion. This made it more difficult to do deep narrow holes than shallow wide holes. Without much more information about the particular job and the way in which it was designed to be employed he did not feel qualified to give any sort of opinion about this relationship.

Mr. D. O. B. MINOGUE (Edward Pryor & Sons Ltd.) asked if the electrical efficiency of the machine was reduced by contamination of the dielectric. If so, at what degree of contamination did the inefficiency become measurable?

Mr. Farley said that as the electrolyte or the dielectric became increasingly contaminated with metal particles breakdown of the dielectric was much easier to accomplish. In the simple relaxation circuit this meant that the capacitor voltage was reduced. The gap broke down more easily. Because the voltage was reduced, the energy stored was reduced according to the square of the voltage. Increasing contamination of the dielectric gave in effect a shorter gap length. The capacitor charged to a lower voltage, but because the gap broke down more quickly the frequency of operation would be increased.

This had two disadvantages. There was then a departure from the optimum conditions as outlined in the paper, so that the power would begin to fall off. If the discharges could be counted upon to be regular, that is to say in the form of an exponential rise of voltage and a sharp fall, followed by the same process repeated indefinitely, the power would fall off exactly as indicated in one of the figures in the paper. In this case it was equivalent to a shorter gap setting, so that the fall-off was fairly gradual. This was on the lower side of the curve in fig. 4, which portrayed relative capacitor power against relative voltage at discharge in per cent. If the charge was carried out to about 71% of full voltage, maximum power would be obtained. With contaminated dielectric an operator would be charging up to a lower relative voltage and therefore the power would fall off theoretically as indicated in the figure.

Further, as dielectric contamination increased the discharges were no longer regular. Any oscillogram of spark discharges at reasonably high power would confirm that. The voltage at discharge, once it began to fall due to contamination, was quite irregular. Some peaks of voltage were small and some were large. This in any given case would depend upon the practical conditions, the circulation of the dielectric and how fast the metal particles could be purged away. The theory went only so far as to show what was shown in fig. 4. If the discharges were still regular in shape and size, the fall-off was roughly speaking linear. It was virtually impossible to say, except in some specific instance, how this was related to the number of milligrams of metal particles per litre.

Mr. K. APPELBEE (Metropolitan Vickers Electrical Co.) said that he had read Mr. Farley's paper with interest, but there was one point on which it seemed that Mr. Farley had not spent much time. That was the question of dielectrics. As spark machines became larger and larger and as faster and faster metal removal rates were obtained, industry

was faced with the problem of having larger and larger filtration plants. The filtration part of the machine with which his company was at present involved was larger than the machine itself, containing several hundred gallons of oil. Was Mr. Farley doing any work on the question of other types of dielectrics besides the conventional kerosene and oil? This was one facet of the problem to which much more research must be directed.

Mr. Farley said that dielectrics at present in use were confined to paraffin for the lower powers and other types of heavier oils for higher powers. He believed that work had been done on using common or garden water, but that had not met with much success. A basic problem attached to any sort of high power working was that working at high power a great deal of metal was necessarily removed. If a considerable quantity of metal was removed, it must go into the dielectric. Therefore, in order to achieve regular working, one must expect to take it out of the dielectric by some form of filtration plant. The system as a whole, considered as a process of removing metal from one place and putting it somewhere else, must be a pipe of uniform cross-section. The filtration plant must be capable of removing the volume of metal which came from the work-piece. There should be no surprise that a large volume of metal had to be removed. There was room for work on processes of filtration and precipitation which would reduce the size of plant for a given amount of metal removed. There was room for research into a dielectric which would more readily support the presence of metal particles. That was the type of approach which an electrical engineer would adopt. Could dielectrics be investigated to find those which were least susceptible to breakdown by metal contamination? Mr. Farley did not know of any work taking place in this country at present on the behaviour of contaminated dielectrics. He would be very interested to hear if anyone else knew of any.

Mr. R. A. Riley (Alfred Herbert Ltd.) asked if there was any method of determining the shape of an electrode to reduce the finishing operation. He had in mind a simple hemisphere. In the beginning the centre of the electrode would contact, and that would have more rapid wear than the periphery of the electrode. He suggested that some form of cone would help.

Mr. Farley said that this important question was one more of electrode design than of circuit technique. It was fundamental in the process that discharge would take place where the gap was shortest and where the corresponding electrical stress in the dielectric was largest. That was at one time a disadvantage and at another time the beauty of the method, in that the discharge would continue to take place at a given point, quite a number of discharges together in some cases, until the gap was opened up to such a level that the maximum electrical stress was transferred to some other part of the electrode. The discharge then transferred itself to there. This was the mechanism by which quite a large surface could be machined out with surprising accuracy.

Mr. Farley thought that Mr. Riley was suggesting that efforts should be made to try to devise some mathematical shape which, after the process of erosion, would finish as a hemisphere of just the right finished size at just the right instant. This was something like a philosopher's stone. Most people would agree that it would be more reasonable to start with electrodes of approximately the finished shape. There was sound economics in this, because whilst one was being knocked out several could be knocked out and used one after the other. This had a number of advantages in practice as far as the availability in production of electrodes was concerned, rather than trying to start with one electrode of a carefully computed shape which would finish a hole of the right size in one go. Mathematicians or physicists might be employed for some considerable time in predicting what shape one might have to start with in order to finish with a perfect hemisphere. In practice nobody would be allowed the time to sit down and carry out this very interesting study. Three or four electrodes of the right type would be knocked out and used one after the other. This was an occasion when the delights of mathematical analysis must give way to the necessities of economics.

Mr. Minogue said that his remarks about contamination of the dielectric had been treated as applying to metallic particles only. What was the effect of the considerably greater quantity of carbon particles produced all the time the machine was functioning? These tended increasingly to contaminate the dielectric with carbon.

Mr. Farley said that the answer to the second part of Mr. Minogue's question was roughly the same as the answer to the first part. The dielectric in its virgin state was a non-conductor. To a non-conductor, from the point of view of electrical field distribution, a particle of carbon would be very little different from a particle of metal. Both carbon and metal were relatively good conductors compared with the dielectric. There would, therefore, be not very much difference in the change in the electrical fuel distribution, and so not much difference in the reduction of the peak voltage on the capacitor and the irregularity of operation. He would not care to express an opinion on whether the shape of the particles was vastly different, but he rather thought that there would be a difference between them. He would not like to say offhand

whether that in itself would affect the fuel distribution within the dielectric. The size and shape of the particles might present different filtration problems, but he could not give a definite answer without specific details of a particular problem.

Mr. F. C. Bird (Walter Somers Ltd.) thought that there was one aspect of the subject about which some delegates would be interested to learn more from Mr. Farley.

It seemed that the energy available from the simpler type of circuit—the capacitor—depended on its size and the voltage available at the terminals. That, in turn, appeared to depend upon the precise condition at which the capacitor would discharge, in other words the gap. Since in a later paper it was stated that the capacitance might vary from one-sixteenth to 300 microfarads, the issue arose whether this governing factor was inherent in the size of the machine or whether in fact the capacitance was variable. If not, it appeared to indicate that in the finishing operation, where the gap had to be low, the discharge would take place more readily. The voltage at which the capacitor discharged would be reduced. In other words, as was well known in practice, the whole of the energy and the success of the process were reduced in order to develop a fine finish. That was a limitation upon the type of machine. If the capacitor could be increased in size whilst maintaining a lower voltage, there was a possibility of increasing the finishing removal rate or of maintaining more closely the original removal rate of metal, so preserving the efficiency of the apparatus to the conclusion of the process, instead of having to tolerate a reduction in its efficiency as a concession to the surface finish desired.

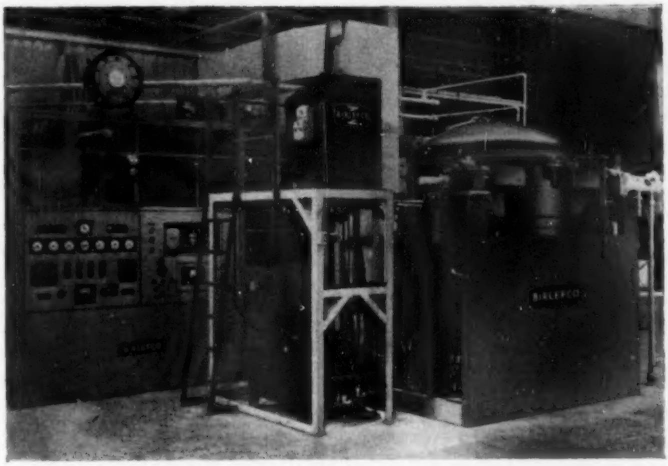
Mr. Bird hoped that Mr. Farley had grasped the issue which he was rather innocently trying to state. Had he any comments to make? Mr. Bird said that he gathered that all the capacitor types were giving place in some respects to those driven by a special form of current generator, and therefore his point might not apply. However, it seemed to be significant even if attention was turned to the other type of revolving energy generator. If it was to be pulsed and the pulses were fixed in their rapidity, the only other variable factor would be the energy of each individual spark. That meant in turn that there would be no control over the finishing.

Mr. Farley said he hoped he had grasped Mr. Bird's point. The important thing to realize about the rotary impulse generator machines was that they were essentially roughing machines, because they used basically a different type of discharge, namely an initiating spark, followed by an arc. Where there was an arc there was more appreciable melting of the surface and some slight extension of the erosion effect to the underlying layers of the surface, but because of the nature of the discharge, and for no other reason, these were essentially machines which one would use for roughing work. Although the power could be varied by a simple series resistance which altered the energy per discharge and the frequency of the discharges remained the same, with this type of machine there was some control over the surface finish. This was bound up inextricably with the control of the power. Although with these machines the surface finish could be controlled, this brought with it a reduction in power. The main field of application would, of necessity, be for roughing.

Turning to the capacitor types, Mr. Farley said that the first thing to realize was that, if the size of the capacitor was increased, the energy per discharge would be increased. At the same time, the frequency of the relaxation oscillations would be reduced. This was not followed in practice when high repetition rates were reached, as Seed and Drubba had pointed out some years ago in a paper in *Engineers' Digest*. There were divergences from practice at high speeds, but at low speeds of repetition it could be safely said that the capacitor to all intents and purposes altered only the energy per discharge. For example, if the size of the capacitor was increased, the energy per discharge was increased, but the frequency at which the discharges occurred decreased, so that the power was roughly the same. To a good approximation, even if the capacitor was reduced to the low values necessary for fine finishing work, the power available should be sensibly maintained.

Theoretically, there was an optimum gap setting which would give a maximum power transfer. In practice, if working at high values of capacitance, every discharge took out a comparatively large chunk from the surface and one would expect the effective gap rate between the work-piece and the electrode to increase. For finishing work the amount of metal removed per discharge was considerably smaller, the surface was much more regular and the gap between the two would get smaller, as was to be expected in finishing work.

The Chairman, thanking Mr. Farley, said that although there would be votes of thanks at the end of the symposium for all the lecturers, as chairman of the morning session he wanted to thank Mr. Farley very much indeed for the trouble and care he had taken in preparing his paper and the way in which he had answered questions. Not being an electrician, the greatest impression left by Mr. Farley on his mind was the sentence in his paper: 'Immediate future developments must, therefore, be in application techniques rather than in devising new electrical circuits.' That was a challenge to those in the drop forging trade.



Vacuum treatment of molten metals

Birlec de-gassing and vacuum refining unit

THE VACUUM MELTING FURNACE has proved an expensive but useful tool in the production of better alloys and of cleaner metals. Stream de-gassing equipment, alternatively, greatly reduces costs, but is only suitable for relatively large batches of metal and in practice its use is limited to large forging ingots. Various ladle de-gassing systems are also in use, but are limited in the degree of de-gassing that can be obtained in a practical time, bearing in mind the difficulty of keeping metal hot in a ladle.

Birlec-Efco (Melting) Ltd. has developed a de-gassing and vacuum refining unit which overcomes many of these problems. It is relatively inexpensive, but gives close control over temperature and pressure. Turbulence of the metal in the vacuum vessel is induced electro-magnetically and therefore cycle times are reasonably short.

Birlefco vacuum refining unit

A unit of this type has recently been installed at the Birmingham works of Henry Wiggin & Co. Ltd. for the vacuum refining of special alloys. Basically it is a 15-cwt. mains-frequency induction-melting furnace housed in a tiltable vacuum tank.

A water-cooled copper induction coil, supported by a magnetically-shielded steel framework, forms the furnace proper. Special insulating techniques and careful design work have eliminated the difficulties of handling high voltages in vacuum, ensuring that no troubles arise through electrical breakdowns within the furnace.

The choice of mains frequency was based not only on the lower cost of the mains-frequency electrical gear when compared with H.F. equipment, but also on the inherently greater degree of turbulence which a mains-frequency furnace imparts to the molten metal. This turbulence stirs the bath thoroughly and brings new metal to the surface, where gases and volatile metals can be drawn off.

The present installation has a rating of 300 kW. and is arranged for connection to a low-tension three-phase supply. 300 kW. gives this unit ample power for melting duty, though for refining service only a maximum rating of 200 kW. would suffice.

The vacuum tank, which houses the furnace, is mounted on trunnions and tilted by twin hydraulic cylinders. The tank movement produces an approximately lip-axis pouring effect from the furnace and a retractable bridge over the top flange of the tank carries the metal stream. Hydraulic controls open and close the vacuum tank lid and pneumatic clamps lock the lid on to the tank. The furnace mouth carries a refractory cover with holes corresponding with a viewing port in the chamber lid. This cover reduces heat losses and cuts down the loss of metal by splashing.

The vacuum pumping lines are connected to the tank concentrically with the tilting trunnion and in this way pumping connections are not demounted when the furnace tilts. The present installation includes a three-stage pump set which gives ample gas-handling capacity over the whole range. Automatic controls maintain the correct pumping sequence and a dust trap protects the pump set from damage by fumes and metal splashes.

Furnace operation

A typical vacuum refining cycle occupies about 1 h. Liquid metal is brought to the furnace by ladle and, when the furnace is charged, the hydraulic gear lowers the lid into position over the chamber and pneumatic clamps lock it in place. The chamber

pressure is then reduced to about 200-300 microns in about 15 min.

During refining sufficient power is applied to the furnace to ensure thorough stirring of the molten metal and to maintain temperature at the desired value.

After vacuum treatment air is admitted back into the furnace, the hydraulic gear raises the lid and the retractable spout is placed in position. The temperature of the metal is adjusted and checked by dip thermocouple and various other checks are made, after which the furnace tilts, pouring the vacuum-refined metal into a ladle for casting or teeming in the conventional way.

Results

The application of vacuum to the melt removes gases and volatile metals. The results obtained so far have proved very satisfactory and the high-temperature properties obtained on vacuum-refined metals have exceeded those forecast, basing the estimates on work done in the laboratory. A standard basic refractory lining is in use and gives satisfactory lives. It is rammed around a normal-type former and presents no special problems. The furnace has produced the desired effects at a fraction of the cost of an equivalent conventional vacuum melter. With a reasonable degree of utilization actual costs are only a few pence per pound of metal treated.

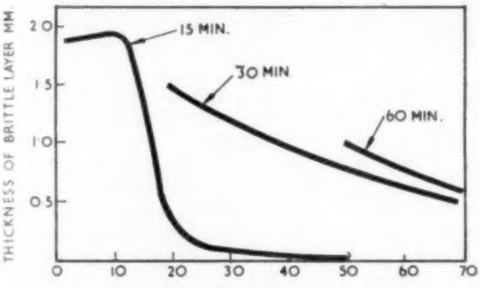
Effect of plastic deformation on the rate of diffusion

STUDY OF THE RATE OF DIFFUSION of elements into metals, and its dependence upon the working of the metal is of interest, since it allows one to estimate the influence of the state of the metal lattice on the mobility of the atoms of various elements through it. Unfortunately, the data on this problem is very limited, but some recently reported Russian work[1] on the diffusion of sulphur into nickel and the influence of the degree of deformation on the speed of diffusion of the element gives a lead for further work.

Specimens of nickel subjected to varying degrees of deformation up to 70% were placed in cast iron boxes, with a small amount of elementary sulphur. The crack between the upper and lower parts of the box was sealed and each box heated in a furnace to 700°C., and maintained at this temperature for various periods of time, 15, 30 and 60 minutes, thus annealing the specimens in a sulphur vapour.

As a measure of the rate of diffusion, the depth of the layer reached by the sulphur was taken (for a definite duration of annealing); this could easily be determined, since the penetration of sulphur into nickel causes the latter to become brittle and brings about a rearrangement of the grain structure, with increased grain size, disappearance of twinning in the grains and sharper marking of the grain boundaries. The thickness of the layer of nickel saturated with the sulphur was thus determined by microscopic examination of the change of structure of the metal.

Fig. 1 shows the results of the experiments.



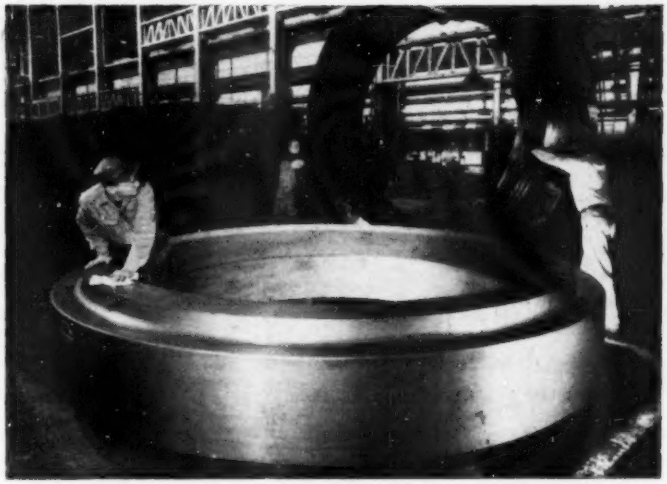
1 *Influence of degree of deformation on the depth of penetration of sulphur into nickel*

With an increased degree of deformation the depth of penetration of the sulphur decreases and at 50% reduction (15 min. anneal) it becomes zero. With small degrees of deformation and 15-minute annealing a slight increase is observed, but this does not apply to longer annealing periods; the decreased thickness of the nickel layer reached by the sulphur with increased degree of working also occurs for 30 and 60 minutes annealing time.

The rate of diffusion is markedly affected by distortion of the lattice, which is increased by plastic deformation; there are many references to the increase of lattice distortion, as observed by the diffusion of X-rays and their decrease in intensity, with increased degree of reduction in cold working. Comparison of these references with the above experimental data shows that the sudden decrease in the rate of diffusion into nickel occurs at the range of reduction where the lattice distortion is the greatest, so that the diffusion process is directly dependent upon lattice distortion.

Reference

(1) Presniakov A. A. *Zhurnal. Tek. Fiz.* **27**, (3), 512.



Forging reactor parts

Typical steel forgings for reactor pressure vessels

THE PRODUCTION of forgings for pressure vessels used in atomic reactors presents many special problems. It is necessary to combine the techniques used to make high-pressure vessels for the chemical industry and low-pressure vessels used for steam generation.

The Bethlehem Steel Company, U.S.A., recently had to produce a number of forgings for atomic reactors at short notice and it was decided to use the SA.302 analysis. This is nominally a low-carbon steel with 1·30% Mn and 0·5% Mo. To improve impact strength, 0·40 to 0·80% Ni was added and the aluminium was de-oxidized.

Of particular concern in production were the following four points in the proposed specifications: (1) The composition called for a high manganese-molybdenum steel; (2) The steel required de-oxidation with aluminium. Aluminium is undesirable in heavy forgings; (3) The forgings had to be liquid quenched. Liquid quenching of massive forgings of varying cross sections is hazardous; (4) Impact properties had to be high and the transition temperature low. Those properties, although easily attained in light sections such as plates, present problems in heavy sections of the large forgings.

Because production had to proceed according to schedule, sound forgings had to be made available at once. Production was started at a plant of Bethlehem Steel Co. on the initial orders for reactor pressure vessel forgings.

Flaking problems

Satisfactory forgings were made—but at a high cost. The rate of rejection was alarmingly high—so high that only the urgency of the situation justified continuing production. Investigation of the condemned pieces substantiated the opinion that the SA.302 analysis was abnormally susceptible to flaking or internal fissures in the heavy section.

Generally, flaking problems may be minimized by the use of longer thermal conditioning cycles. This step was taken and, while some improvement was evident, the results were still not satisfactory.

At the same time, the use of aluminium was discontinued and further improvement was noted. It was apparent that the programme depended on the immediate development of a new composition which would ensure continuous production of sound forgings.

With the co-operation of the prime contractors, fabricators, and the Naval Reactor Branch of the Atomic Energy Commission, Bethlehem undertook hurried research to develop a composition better adapted to the manufacture of heavy forgings, and at least equal to the SA.302 modified analysis in tensile and impact properties and in weldability. The programme, which involved testing of small laboratory heats as well as the manufacture of production forgings, was completed in four months.

New alloy steel developed

As a result of this work, a composition was developed which produced material equal in the desired characteristics of tensile and impact properties and weldability.

The nominal analysis of the new composition is 0·20% C; 0·65% Mn; 0·70% Ni; 0·35% Cr; and 0·60% Mo. Weldability tests proved the analysis was equal in all respects to the former com-

position. Tensile and impact properties were equal to those of the original SA.302 modified analysis.

Techniques for liquid quenching the forgings and for machining close to final contour before quenching, to obtain the desired properties at the most highly stressed locations, were found to be adaptable to the new composition. Production was started on the new analysis and more than 50 have been produced at Bethlehem without rejection due to flaking.

The properties of the new alloy steel have been more than comparable to those of the earlier analysis, and fabricators have indicated that the weldability of the new composition is equivalent to the former. The performance on forgings produced without delays and with only normal rejections has justified the use of the new composition for production of atomic power reactor pressure vessels. It is now available to all producers.

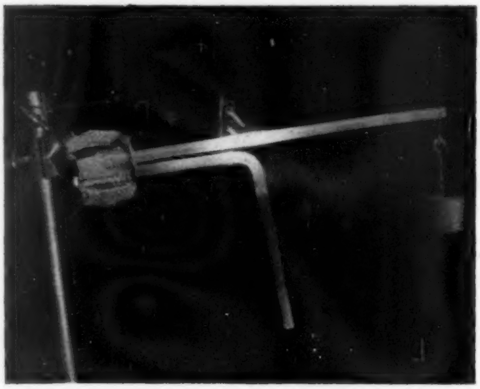
New transparent ceramic

A NEW ceramic material has been announced by the General Electric Co., Schenectady, N.Y., U.S.A. 'Lucalox,' as the new material is called, is made from powdered aluminum oxide. It is closely related to sapphire and ruby gem stones, which are single-crystal aluminum oxide. But this polycrystalline form of the same compound is reported superior to these gems in its ability to withstand high temperatures without deforming.

The unique characteristics of 'Lucalox' result from the fact that the microscopically small pores, or 'bubbles,' that are normally found in ceramic materials have been entirely removed, a feat that had been previously considered impossible. Because of the elimination of the pores, it is possible to read through a sheet of 'Lucalox' when it is laid flat upon a piece of paper. At greater distances it appears translucent, resembling frosted glass. At least 90% of the light in the visible spectrum is transmitted through the new ceramic.

The basic material of 'Lucalox' is fine-grain, high-purity aluminum oxide, or 'alumina.' The powder is pressed at room temperature, then fired at temperatures that are higher than usual for ceramics.

'Lucalox' was first made by Dr. Robert L. Coble, of the General Electric Research Laboratory. Following his first research, important contributions were made by Dr. P. D. S. St. Pierre, Dr. Edward Stover and Arno Gatti. The problems of making the process commercially feasible are being explored by Dr. Charles A. Bruch.



A bar of 'Lucalox,' the new transparent ceramic, and a bar of fused quartz are heated by a blow torch. At a temperature of 1,290°C. the bar of quartz bends under its own weight, whereas the bar of 'Lucalox' easily supports a 50g. weight, even when the temperature reaches 1,760°C.

Possible applications

One example of possible industrial use would be high-intensity incandescent and discharge lamps, which are now limited by the heat resistance of their transparent envelopes, in some cases. Fused quartz, which is often used for high-temperature lamps, performs satisfactorily up to 980°C.; 'Lucalox' is stable at temperatures close to 1,980°C.

Another likely application for 'Lucalox' is in the banks of infra-red lamps that are used to test the heat-resistance of missile nose cones and other space vehicle equipment. It may also be used as an electrical insulator and as a material for gem bearings in delicate equipment.

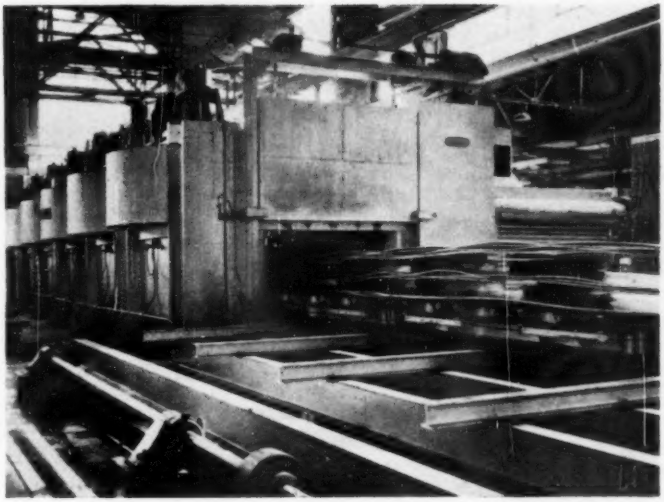
Present ceramic materials can be divided into three general categories:

Conventional ceramics, such as porcelains, in which the crystals are bonded together by low-melting glass—these approach, but do not reach, the 100% density of the new material. They are limited by the low melting point of the bonding glass.

Oxide ceramics, more or less single phase—these are stronger than the porcelains, but, filled with light-scattering pores, they are opaque.

Single crystals, such as sapphire and ruby—these are transparent, but are limited in size and shape and are extremely difficult to fabricate.

'Lucalox' has a metal-like structure, in that its crystals are bonded directly to one another, with neither pores nor a glass matrix between them. Information gained from the study of this material may consequently be applied to powder metallurgy.



New plant at aluminium works

Aluminium slabs being loaded into 65 ft. capacity G.W.B. furnace at the Northern Aluminium Co. Ltd., Banbury

FOR THE PAST FEW YEARS the Northern Aluminium Co. Ltd. have been carrying out a large-scale development programme involving the introduction of much new plant and handling equipment. Included in this programme was the installation of a new batch-type furnace which was designed and erected at the Banbury works by G.W.B. Furnaces Ltd. The Banbury works are engaged in producing a wide range of sheets, coils and discs, both in aluminium and a variety of aluminium alloys. Previously the mills engaged in rolling aluminium sheet could roll a maximum width of 5 ft.; now the new mills can produce widths of up to 6 ft. 6 in. and the G.W.B. furnace has been specially designed to fit in with this new development. Ingots of aluminium 8 in. thick are hot rolled down to approximately 0·300-0·500 in. Some work hardening takes place and consequently slabs have to be annealed before being cold rolled to lighter gauges. The furnace can accommodate loads up to 16 tons for slab lengths of 65 ft. and widths of 6 ft. 6 in.; the maximum temperature is 600°C., although normal operating temperatures are somewhat lower. A three-shift system is at present being worked. The furnace has a rating of 1,000 kW. arranged in six independent and automatically controlled zones. The high rating enables cycle times of as low as 4 h. to be achieved.

Description of furnace

The heating chamber is lined throughout with heat-resisting alloy, backed by a thick wall of Moler insulating bricks, thus reducing heat losses to a minimum. The furnace casing is constructed from sheet mild-steel casing braced with mild-steel rolled sections and fitted with a mild-steel front plate. Understructure supports the furnace clear of the ground and permits free air circulation under the hearth. A cast-framed, refractory-faced, fully insulated and counterbalanced door, driven by electric motor, minimizes heat losses at the furnace entrance.

Heating elements of nickel-chromium strip, arranged upon removable plugs, are situated in the roof of the chamber, and each zone is fitted with a forced-air circulation system directed cross-flow from the fan, through the heating elements contained in the ducted portion of heating chamber, down into the treatment chamber, and back into the fan for recirculation. A double-cased baffle of heat-resisting alloy, packed with a layer of insulation, is fitted in the roof of the chamber, separating the heating elements from the actual working area, thus preventing radiation on to the charge. The elements are suspended edge on to the air stream between the roof and the insulated baffle by a hook suspension method, ensuring maximum support and preventing 'element flutter.'

On each side of the working chamber a system of equally spaced and parallel baffles extend fully down the length of the chamber. Each baffle is independently adjustable to direct the air flow in such a manner as to give the desired flow characteristics and equalize the temperature throughout the work-

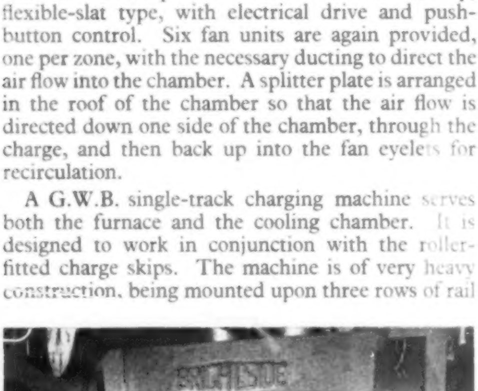
ing chamber. A section of the insulated fan scroll is removable to facilitate inspection of both the heating elements and the fan unit.

Six air-circulating fans are fitted, one per zone, each fan capable of delivering 30,000 cu. ft. air min. Each unit comprises a statically and dynamically balanced centrifugal fan mounted on a high-tensile steel shaft, carried in a robust cast bearing bracket fitted to the cross bracings of the roof of the furnace casing. The bearing bracket is fitted with dual-purpose ball and roller bearings and provided with oil seals in the base of the unit, while a heat-dissipating rotor is fitted to the shaft immediately above the furnace casing to reduce the bearing temperature. The fan shaft is driven through adjustable Vee ropes by an independent totally-enclosed electric motor. Each fan unit may be withdrawn through the side of the furnace casing.

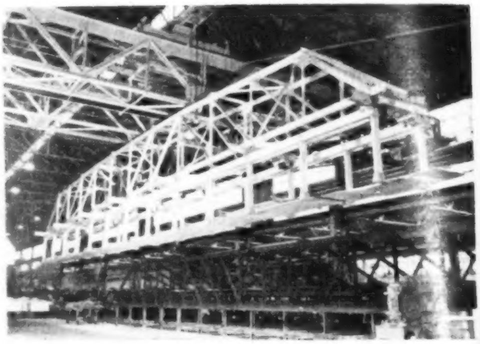
Cooling chamber

With heat-treatable alloys, in order to obtain fully-annealed material, a slow cool is essential. To ensure this a cooling chamber, similar in size to the heating chamber, has been incorporated in the installation. The cooling chamber is constructed from rolled-steel sections covered with non-combustible asbestos panels. The door is of the roll-up, flexible-slat type, with electrical drive and push-button control. Six fan units are again provided, one per zone, with the necessary ducting to direct the air flow into the chamber. A splitter plate is arranged in the roof of the chamber so that the air flow is directed down one side of the chamber, through the charge, and then back up into the fan eyelets for recirculation.

A G.W.B. single-track charging machine serves both the furnace and the cooling chamber. It is designed to work in conjunction with the roller-fitted charge skips. The machine is of very heavy construction, being mounted upon three rows of rail



1 *'Breaking down' the ingot in the Brightside hot-rolling mill*



2 *The King 'Mansaver' grab carrying aluminium slabs to the next stage*

wheels for traversing and a 'go-getter' facilitates charging and discharging. The overall length of the furnace and charging machine is approximately 160 ft.

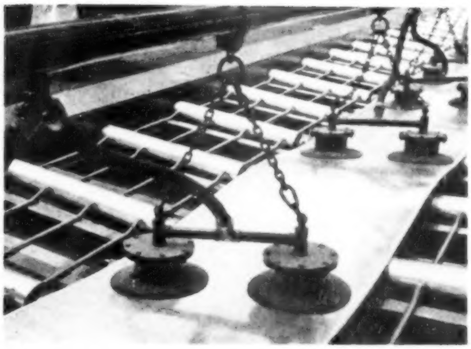
Temperature control

Temperature control in such processes is critical, and this is provided automatically through an instrument cubicle. Six Integra, Leeds and Northrup indicating controllers are provided, one for each zone, and a six-point recording instrument allows a positive visual check on thermal conditions throughout the process cycle. A Venner 15-day automatic time switch is incorporated in the panel, together with six green lamp bezels indicating which element zones are on and one red lamp bezel labelled 'equipment alive.' The switchgear is contained in a separate contactor cubicle and comprises six furnace zone triple-pole contactors, six fan motor contactors and one door drive motor contactor. Adequate protective devices are incorporated; safety contacts are arranged to cut off the supply to the heating elements in the event of accidental overheating; a limit switch is fitted to the furnace door, cutting off the supply to the heating elements when the door is in the raised position, and one Ellison oil-immersed circuit breaker allows the whole installation to be rendered 'dead.'

Mechanical lifting of slabs

The handling of larger and heavier aluminium slabs is now made possible at the Banbury works by the installation of two mechanical lifting devices made by Geo. W. King Ltd., Stevenage, Herts., which will handle slabs of up to 85 ft. long singly and in batches.

The production of aluminium strip at Banbury begins with the remelting and alloying of the virgin metal. Commercial aluminium, of 90·0-99·5% purity, is delivered to the fabrication plant in the



3 *Suction discs of the King de-piling crane in contact with slab*

form of ' pigs ' or ' notch-bars '; in the remelting process other materials are added to adjust the composition to that of the alloy required.

Ingots for rolling are cast by the semi-continuous process, in which the metal is poured into a water-cooled mould with a withdrawable base mounted on a hydraulic ram. The sides of the mould are only a few inches deep and are cooled with an abundance of water. In the very short time, therefore, that it takes to fill the mould the metal at the bottom solidifies and contracts away from the sides of the mould. The hydraulic ram supporting the bottom plate is then slowly lowered as the solidified metal comes through and pouring proceeds continuously until the required length of the ingot is reached. Rough edges and sides formed during casting are required to be removed or ' scalped ' before rolling, and this is carried out by large milling machines.

Pre-heating, the necessary preparatory to the primary hot-rolling process, is carried out in furnaces adjacent to the start of the hot-rolling line, from where the ingots are extracted singly by heavy-duty mechanical tongs and placed on a receiving table. Under the control of an operator the hot ingot, weighing up to 4,000 lb., is carried on the live roller table to a Brightside 84-in. hot-rolling mill for ' breaking down.' Before entering the rolls the ingot is straightened and centralized by hydraulic rams. Both mill rolls and tables are reversible and the ingot passes backwards and forwards until its thickness has been reduced from 9 in. to less than ½ in. (fig. 1).

The slab, which may be as long as 85 ft. at this stage, is now passed through a Rhodes guillotine, where ragged ends are cut, and on to a Loewy edge trimmer, where rough and uneven edges are removed. Finally, it comes to rest on a slab-piling conveyor unit, where all the slabs coming through the mill are allowed to cool.

At this point the King ' Mansaver ' grab lifts the whole pile of up to 40 slabs and takes them to the loading bay for the next rolling process, either directly or via the annealing furnace, where work hardening is removed and ductility restored (fig. 2).

The King ' Mansaver ' is an electrically-operated grab of 10½ tons capacity, having 13 pairs of load-carrying legs spaced at 6-ft. centres and supported by two double-channel loading-bearing beams running the full length of the grab. The load beams are attached to the outer end of seven pairs of opposed rack beams running between cast-iron flanged rollers; these are motor driven for opening and closing to suit the width of the load through totally-enclosed worm gear units and chain incorporating a slipping clutch to give motor overload protection. The whole grabbing unit is integral with a 72-ft. box lattice girder arranged for two-point suspension from an overhead travelling crane, whose operator controls all grabbing and travelling operations. Both the grab and lattice girder structures are constructed of 95% aluminium alloy sections.

The slab-lifting equipment

For the next operation it is necessary for each slab to be lifted separately from the batch and placed in position for intermediate rolling, and for this purpose Geo. W. King Ltd. have designed and installed an overhead de-piling crane, which, by the use of rubber suction discs, lifts a single aluminium slab swiftly and safely from the top of the pile.

The King de-piling crane comprises a lifting beam, which also acts as a suction manifold, to which 44 suction discs are attached by load-bearing chains and connected by flexible air hose. A vacuum pump creates the necessary suction when the discs make contact with the aluminium slab, and the whole beam is hoisted by 10 wire ropes attached to separate drums mounted on a common shaft located within the box lattice framework of an 87-ft. span electric overhead travelling crane (fig. 3).

All or just isolated groups of suction discs may be used according to the length of slab being handled. Each disc is also fitted with an automatic cut-out to prevent loss of vacuum should an irregular size of slab cause failure to contact. All crane and vacuum motions are controlled from a desk at floor level, where the operator has a full view of the area served by the crane.

Intermediate rolling, carried out by a Robertson four-high cold roughing mill, reduces the thickness of the slab still further after which it is coiled and conveyed to other sections of the works for further rolling, tempering, shearing and slitting and other processing according to the various uses for which it is finally intended.

NEWS

NICKEL AND PLATINUM METALS EXHIBITION

AN EXHIBITION, to which over 12,000 designers and technologists were invited, was staged by the Mond Nickel Co. at Marlands Hall, Havelock Road, Southampton, from October 27-30. The exhibition, which featured the properties of nickel, nickel-containing materials and the platinum metals, was opened by Rear-Admiral W. F. B. Lane, D.S.C., M.I.MECH.E., Director of Marine Engineering, Admiralty.

The exhibition was divided into sections dealing with mechanical and physical properties, corrosion-resistance, electrodeposition, strength at high temperatures, toughness at sub-zero temperatures and welding. Working demonstrations, illustrations and specimens of materials were shown and each day a number of films were given relating to particular aspects of the exhibition.

One of the most interesting features was a specially designed working model of a rhodium-plating plant. This model is the first automatic rhodium plating plant ever built and it has been designed for use at the company's exhibitions. The plant has a capacity of 240 items an hour and, handling eight pieces at a time, completes the plating operation in 2 min.

Marine developments

From M.T.B.s to the latest in super-tankers is the story of the development of the nickel-aluminium bronze propeller, and it was appropriate that this marine application of nickel should be featured.

In 1942 the Admiralty adopted nickel-aluminium bronze propellers as standard equipment for M.T.B.s and in August of this year a propeller with a cast weight of about 50 tons was cast at the works of Lips N.V., Drunen, Holland. This new giant will be the only propeller fitted to the Tidewater Oil Co.'s new 72,600-ton super-tanker being built at Dunkirk by Ateliers et Chantiers de France.

Nickel-aluminium bronze propellers have the advantage over those cast from high-tensile brass in that they are lighter, stronger and more resistant to corrosion-erosion. Reduced weight means less wear on shaft bearings, less power required and allows increased cargo-carrying capacity. The use of nickel-aluminium bronze propellers means a saving in fuel costs and, because of the strength of the material, lower maintenance costs.

Improved gunmetals

All the standard gunmetals in use today have been evolved by trial and error and none of them is capable of providing the ideal combination of requirements needed for the production of quality castings.

One of the features at the exhibition was an improved gunmetal. The new alloy, 85/6·5/3/3·5/2 Cu-Sn-Zn-Pb-Ni, has stable and much better mechanical properties at both atmospheric and elevated temperatures than 85/5/5/5 gunmetal and it still retains the same adaptability to the production of pressure-tight castings. When properly made, castings in this alloy have a 0·1% proof stress of around 8 tons/sq. in. with a maximum stress of 16-17 tons/sq. in. in sections up to 3 in. thick. The mechanical properties can now be related to those obtained from separately cast test bars.

Exhibition at Hatfield Technical College

As part of the course entitled 'Nickel Survey' being held at Hatfield Technical College, Herts., Henry Wiggin & Co. Ltd. was invited by the College Department of Mechanical and Production Engineering to stage an exhibition.

The exhibition, which is open from November 17-19, will not only be an integral part of the course on nickel and its alloys, but will be of great interest to local industry.

In addition to demonstrations of the properties of Wiggin alloys—heat resistance, corrosion resistance, electrical resistance and special physical properties—the exhibition will include complete aircraft gas turbines, one of the early Whittle engines and over 300 examples of the type of plant component and sub-assembly for which Wiggin materials are used.

Mr. D. D. Carrington, B.SC., chief engineer of Walter Somers Ltd., is to read a paper at the British Iron and Steel Research Association's annual Forgemasters' Conference at Bournemouth this month.

The paper will discuss the conversion of the company's heavy forge from solid fuels to oil, and in particular the development of one 32-ft. bogie-hearth furnace, which included the making of a model to study the flow of gases; and a certain amount of investigation, both here and abroad, into the problems of heating large pieces of steel—up to 65 tons—with high-temperature oil flames.

Several unusual features were incorporated in this furnace and the results from it and the experience gained in its design and construction provided information which the company has used in the designing and building of further units. Seven furnaces have now been constructed and are operating satisfactorily.

British exhibition in New York

The Engineering Centre, Birmingham, has announced its support for the British Exhibition to be held in New York from June 10-26 next year. Mr. A. J. Cox, general manager, said he had booked space at the forthcoming exhibition which would enable between 50 and 60 firms to take advantage of the special facilities the Engineering Centre had to offer and so be able to show their products to American buyers on an economical basis.

This will be the first comprehensive all-British exhibition and Trade Fair to be held in the U.S. and, occupying all four floors of the Coliseum Building, will be nearly twice as large as the recent Russian exhibition in the same place.

Major exhibitors besides the British Government will be the British motor industry, who have booked an entire section of about 10,000 sq. ft., the British shipbuilding industry, the iron and steel industry, the Port of London Authority and the General Post Office.

£1-million order from China

An order worth over £1 million sterling for hundreds of tons of British 'Staybrite' stainless steel has been placed with Firth-Vickers Stainless Steels Ltd. by the Chinese People's Republic.

Deliveries of the steel under the order will start at the end of October and shipments will go on until April of next year. The contract followed a visit by a Chinese technical mission to the company's Sheffield works. It is believed that the steel will be used by China in the development of industrial and chemical plant.

The Chinese order was negotiated in conjunction with M. D. Ewart & Co. Ltd. Firth-Vickers, who are Europe's biggest manufacturers of stainless and heat-resisting steels, are also completing considerable orders for stainless steel from Russia.

PEOPLE

IT IS ANNOUNCED on behalf of the English Steel Corporation Group of Companies that the following have been appointed special directors of English Steel Corporation Ltd., the Parent Company of the Group:

K. Chatterton, A.M.I.C.E., chief engineer, Parent Company. Mr. Chatterton joined the Corporation in 1958 after a distinguished career in steel and engineering in India and is responsible for all constructional and engineering activities of the Parent Company.

A. M. Simmers, A.C.A., secretary and chief accountant, Parent Company. Mr. Simmers joined the Corporation in 1955, having previously been secretary and chief accountant of Firth-Vickers Stainless Steels Ltd., of which company he is now a director.

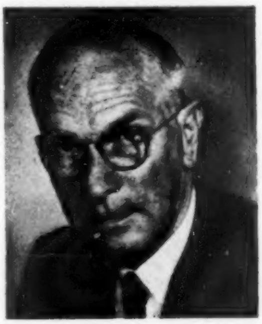
A. Taylor, A.C.A., chief accountant, Subsidiary Companies. Mr. Taylor joined the Corporation in 1936 and is responsible for all accounting procedures affecting manufacturing and selling operations of the Group.

Mr. C. A. McNeill, C.G.I.A., M.A.I.E.E., has joined the technical sales staff of the Electric Resistance Furnace Co. Ltd. at their Midlands Area Office in Birmingham. Mr. McNeill is an experienced electrical engineer who has specialized in electric furnaces for many years. He was formerly technical sales manager of another furnace manufacturing company.

Mr. M. J. Parsons, who has worked for many years with Edwards High Vacuum Ltd., has joined the sales organization of the Electric Resistance Furnace Co. Ltd. at their Head Office in Weybridge, Surrey. He will specialize in vacuum heat-treatment processes and equipment.

Mr. Stanley C. E. Lewis has been appointed group supplies manager and a member of the Motor Car Body Divisional Board of the Pressed Steel Co. Ltd., Cowley, Oxford.

Mr. Lewis entered the service of the Pressed Steel Co. Ltd. in May, 1937, as a purchasing officer, where his duties were mainly at Cowley until the mid-war period. During the latter part of the war he opened and ran an office in Newport on behalf of Pressed Steel, mainly for on-the-spot negotiations with the South Wales steel manufacturers.



Mr. S. C. E. Lewis

After the war Mr. Lewis extended his personal contacts with sheet-steel mills in this country, the U.S.A., Germany, Holland, France, Belgium and Italy. From his extensive travels abroad he has acquired first-hand knowledge of the development of the continuous wide strip mill.

Mr. M. J. S. Clapham

Mr. Michael J. S. Clapham has been appointed chairman of I.C.I. Metals Division from January 1, 1960, in succession to **Dr. Maurice Cook,** C.B.E., who retires from the company's service on December 31, 1959. Mr. Clapham has been joint managing director of I.C.I. Metals Division since October, 1952.

From King's College, Cambridge, where he took an Honours Degree in classics in 1933, Mr. Clapham joined the University Press, Cambridge, as an apprentice. After three years with Lund Humphries & Co. Ltd., the Bradford printers, he joined I.C.I. Metals Division in 1938 to assist in running the Kynoch Press, of which he became manager in 1940. In 1942 he was seconded to the Directorate of Tube Alloys (Atomic Energy), Department of Scientific and Industrial Research, to develop the work started in the Kynoch Press on producing barriers for an isotope diffusion plant. In 1944 he was appointed personnel manager and, a year later, personnel director of I.C.I. Metals Division.

Mr. Clapham is a director of Pyrotenax Ltd., Yorkshire Imperial Metals Ltd. and Imperial Aluminium Co. Ltd. He is chairman of the Non-Ferrous Wrought Metals Export Group and a vice-president of the British Non-Ferrous Metals Federation.

A close interest in education has always been one of Mr. Clapham's preoccupations, both in the sphere of his industrial activities and outside. He was for some years a member of Birmingham Education Committee and is a Life Governor and a member of the Council of Birmingham University. In 1956 he was a group chairman at the Duke of Edinburgh's Study Conference on the Human Problems of Industrial Communities and is a member of the Albemarle Committee, appointed by the Minister of Education to report on the Youth Service in England and Wales.

A native of Cambridge, Mr. Clapham is 47. He is married with three sons and one daughter.

Dr. Maurice Cook has been chairman of I.C.I. Metals Division for the past two years and is a director of Yorkshire Imperial Metals Ltd.

Dr. Cook, PH.D.(CAMBRIDGE), D.SC.(MANCHESTER), joined the Research Department of Kynoch Ltd. in 1926. He was appointed research manager of the Metals Group of I.C.I. in 1938 and director in charge of Research and Development, Metals Division, in 1942. He became joint managing director in 1951 and chairman in 1957.

An extremely well-known figure in the world of metals, Dr. Cook has served on the General Council of the British Standards Institution, the Inter-Service Metallurgical Research Council, the Welding Research Council,

the Council of the Electrodepositors' Technical Society and the Ministry of Supply Metallurgy Committee.

A former president of the Institute of Metals, Dr. Cook is also a past president of the Institution of Metallurgists (of which he is a Founder Fellow). He is chairman of the British Non-Ferrous Research Association, a vice-president of the British Non-Ferrous Metals Federation, a member of the Board of the British Nuclear Energy Conference and a member of the General Board and executive committee of the National Physical Laboratory.

In 1956 he was awarded the Platinum Medal of the Institute of Metals in recognition of his contributions to the science of metallurgy, to the non-ferrous metal industry and to the welfare of the metallurgical profession.

Mr. G. Ronald Pryor, M.I.PROD.E., has been elected president of the Institution of Production Engineers for the year 1959-60. The award of the highest honour that the Council can bestow is a fitting tribute to a man who has worked untiringly, and with notable success, for the advancement of the Institution and the profession of production engineering.

Mr. Pryor has served on the Council continuously since 1945, and was chairman from 1954-56. In 1956 he led the U.K. delegation to the Delft Conference, initiated by the Institution, on Teaching of Production Engineering at University Level, and in 1958, jointly with Mr. J. E. Hill, he headed the Institution's delegation to Poland. He takes a keen interest in production engineering research and has served on the Council of the Production Engineering Research Association of Great Britain since 1950, and on the Executive Committee of this body since 1951.

Born in 1901, Mr. Pryor was educated at Wellington College, Salop, and in 1919 was apprenticed to the family firm of Edward Pryor & Son Ltd., Sheffield, where he is now the chairman and managing director. He is also chairman of Punch Forgers Ltd., of Sheffield.

He is a past president of the Sheffield Section of the Institution and also a past chairman of the Sheffield Section of the Institute of Industrial Administration, of which body he was elected a Fellow. He has served on the Council of the Sheffield Chamber of Commerce since 1951, and was subsequently appointed vice-chairman of the Education Committee of the Chamber.

Mr. W. H. Statham

Mr. W. H. Statham has been appointed area representative of Birlec Ltd. for South Wales and will have his headquarters at Associated Electrical Industries Ltd., Mervyn House, Frederick Street, Cardiff (Cardiff 28511). Mr. Statham joined Birlec Ltd. in 1946 and, prior to his new appointment, was a sales engineer in the Furnace Division of the company.

Mr. A. G. Shaw

Uddeholm Ltd., of Crown Works, Northwood Street, Birmingham, 3, have promoted **Mr. A. G. Shaw,** formerly senior Midland Area representative, to be Midland Area manager. In his new position Mr. Shaw will be responsible throughout the Midlands for sale and service in the Tool Steel and Heat Treatment Divisions of Uddeholm Ltd., the British associate company of Uddeholms A.B., Sweden.

Mr. P. L. Lowrie, B.SC., A.M.I.E.E., and **Mr. W. H. D. Campbell,** M.A., F.C.A., have been appointed directors of the British Geco Engineering Co. Ltd. Induction Heating Division, Edenbridge, Kent.

OBITUARY

It is with deep regret that we have to report the death of **Mr. Basil Doncaster** last month at the age of 74.

Basil Wilson Doncaster joined the firm of Daniel Doncaster & Sons Ltd. in 1909 and was chairman from 1948 to 1955, when he retired. He was the great grandson of the founder of the firm whose trade mark was granted by the Cutlers' Company as far back as 1778.

Mr. Doncaster was prominently concerned with the affairs of the Drop Forging Association in its early days and was a frequent attender at meetings.

Mr. Doncaster was a graduate of King's College, Cambridge, where he took a degree in engineering. He was a former treasurer of the Edgar Allen Institute and the Sheffield Repertory Company. He was a Freeman of the Cutlers' Company and former member of the Sheffield Chamber of Commerce. In his younger days he had been a keen cricketer and was a director of Sheffield United Cricket and Football Club Ltd.

We also regret to have to report the death of **Mr. P. S. Thomas,** sales manager of Portway Forgings Ltd., who died following a road accident last September.

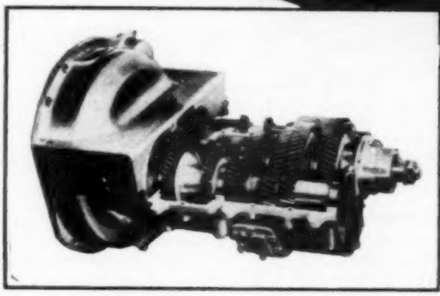
We are deeply sorry to learn of the death of **Mr. T. P. N. Burness,** chairman of Ambrose Shardlow, which occurred very suddenly last October at Newark.

Mr. Thomas P. N. Burness was in his seventieth year. He started his career as a sea-going engineer officer in the Clan Line. He served with Ruston & Hornsby, of Lincoln, and was for many years managing director of William Asquith & Sons, of Halifax. He became chairman of Ambrose Shardlow in 1955.

Mr. Burness was a regular attender at the annual conventions and at the annual banquet of the N.A.D.F.S. During his period as chairman of Ambrose Shardlow he had taken very considerable interest in the Association affairs.

NICKEL ALLOY STEELS

for long trouble-free mileage



Over a half-million miles and nineteen years of service have not impaired the efficiency of the David Brown gearbox fitted to this E.R.F. lorry operated by Samuel Drake and Sons, Ltd., Honley, Huddersfield. During a recent major overhaul after 582,000 miles of running, the gearbox was found to be in excellent condition and was replaced for further service, with a rebuilt engine.

Throughout their range of gearboxes, the David Brown Automobile Gearbox Division, Huddersfield, employ nickel alloy case-hardening steels, types En 34, En 36 and En 39. These steels are used to ensure reliability of the gears and shafts under the heavy and sustained stresses encountered in their operation.

TYPICAL CORE MECHANICAL PROPERTIES OF

EN36

3 per cent nickel-chromium-molybdenum case-hardening steel

SIZE	HEAT TREATMENT	MAXIMUM STRESS t.s.i.	ELONGATION per cent	IZOD ft. lb.
$1\frac{1}{8}$" dia.	Oil quenched 780°C.	72·0	19	69
$2\frac{1}{8}$" dia.	Oil quenched 860°C. Oil quenched 780°C.	62·7	19	67
3" dia.	Oil quenched 860°C. Oil quenched 780°C.	59·7	22	72

Additional benefits to be gained from the case-hardening nickel steels such as En 33, En 34, En 36 and En 39 include ease of heat-treatment, minimisation of processing distortion and general reliability.

Send for 'The Mechanical Properties of Nickel Alloy Steels'

MOND NICKEL

The Mond Nickel Company Limited · Thames House · Millbank · London · SW1

TGA 21/2W

NEW PLANT

High-speed handling of hot samples

Lamson Engineering Co. Ltd., Hythe Road, London, N.W.10, announces the introduction of a new air-tube system designed to carry steel samples at high speeds between furnace and analytical laboratory. This system is operated by compressed air and can carry samples weighing 4 lb. at high temperatures and at speeds of 40-50 m.p.h. (fig. 1).

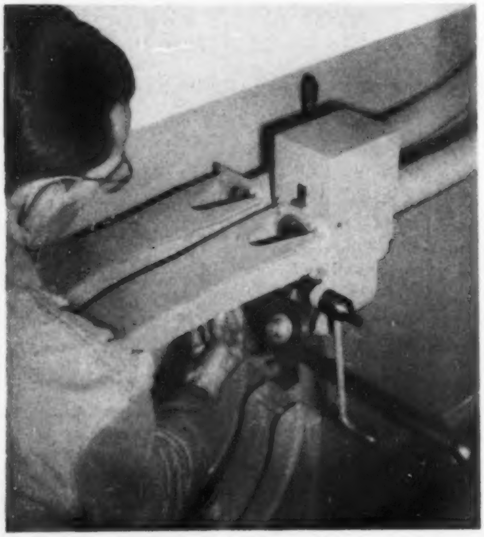
The high-speed analysis of samples in the course of a melt is of great importance in modern steel production and the time spent in transferring the sample from furnace to laboratory does affect the rate of production, and the handling of samples while still hot can have distinct advantages.

The carrier in which the sample is conveyed has internal measurements of 2 in. dia. by 4 in. long. The head is in the form of a sleeve fitting over the carrier. The tubing in which it travels is 3 in. dia. and can be laid underground, overhead or inside ducts. When the carrier is inserted in the end of the tube a door is shut, automatically operating an air-valve which admits compressed air for a predetermined period to propel it to the receiving end. The door then opens to allow another carrier to be inserted or one to be received. Normally only one tube is needed with carriers passing in both directions. Where traffic is heavy, however, a two-way system can be installed, using each tube for one direction only.

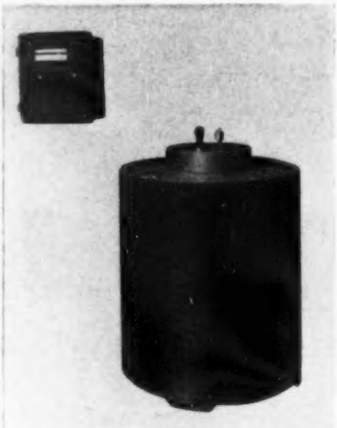
This system has been tested by a leading steel manufacturer. The distance of 1,250 ft. between the furnace and laboratory is traversed in 17 sec. at over 40 m.p.h.

Electric resistance melting non-ferrous metals

The Hedin electric resistance furnace for non-ferrous metals, shown in Fig. 2, has been designed to meet a growing demand for small melts. It is a typical lift-out crucible type, which will melt 50 lb. per charge. It is rated at 14 kW. and will melt 10 lb./kWh. The furnace has a temperature range of 1,400°C. and artificial atmosphere inlets are provided to prevent oxidization during the melting cycle. The atmosphere may be piped from an exothermic gas generator or from cylinders obtained from the B.O.C.



1 *A carrier being inserted into the Lamson steel sample air-tube*



2 *An electric resistance furnace by Hedin Ltd.*

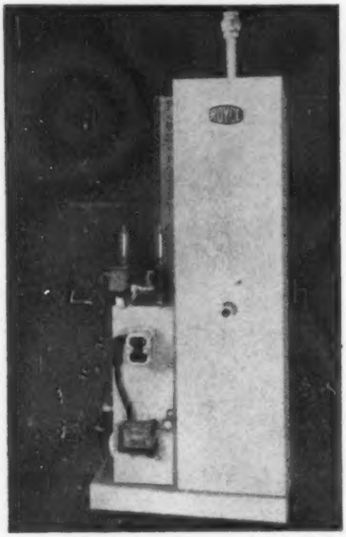
Further advantages are that it is quiet in operation, free from contamination and under accurate temperature control. The only maintenance required is an occasional change of elements, which can be done without in any way disturbing the construction of the furnace. The elements are of the silicon carbide type. The furnaces are built in various sizes up to 110 lb., although larger furnaces can be built as necessary.

Small exothermic gas generator

A compact and economical protective atmosphere generator, shown in Fig. 3, has been developed by Royce Electric Furnaces Ltd., Walton-on-Thames. It is rated at 150 cu. ft. of prepared atmosphere per hour, the whole plant occupying a floor area of less than 3 ft. square. Larger units with capacities ranging up to 2,000 cu. ft/h. are also available.

The exothermic gas is obtained by the controlled combustion of town's gas. The products of this combustion are then cooled to separate the excess water vapour and then purified free from sulphur and passed direct to the heat-treatment furnace. The volume of prepared atmosphere produced is governed by the degree of combustion permitted in the combustion chamber. With partial combustion as required, for instance, in the bright annealing of steel, the yield of atmosphere is approximately three times that of the raw gas burnt and the total electrical consumption is less than 150 W./100 cu. ft. of atmosphere. The degree of combustion permitted depends upon the furnace conditions required.

The combustion chamber, which is lined with high-quality refractory, is specially constructed with refractory baffles to give the requisite temperature and turbulent flow. To conserve heat and give temperate working conditions the lining is backed by a wall of thermal insulating bricks, the whole being enclosed within a gas-tight casing.



3 *Royce exothermic gas generator*

From the combustion chamber the burnt gas passes through a water-cooled collecting duct to a heat exchanger, which effectively cools the gas and removes the excess water vapour. Finally, the gases are purified in a vertical desulphurizing retort containing iron oxide.

High-temperature ammonia dissociators

For some years the use of 75% hydrogen/25% nitrogen mixtures (derived from cracked ammonia) has grown steadily. More recently the high-temperature cracker has increased in popularity, as it obviates the necessity of water scrubbing to remove residual ammonia. In consequence the benefits of the very low oxygen and water vapour concentrations obtained in ammonia crackers are maintained without the high capital cost of additional drying and other purifying equipment.

Using a specially developed catalyst with exceptionally long life and high activity, high-temperature ammonia crackers are now being produced by the Gas Atmospheres Division of the Incandescent Heat Co. Ltd. to the design of the Drever Co., Bethayres, U.S.A. These plants have outputs from 150 to 5,000 s.c.f.h. and are produced in 10 standard sizes.

Detecting water in oil quench tanks

The presence of water in oil quenching tanks is one of the greater hazards to a safe operating schedule. As a means of promoting safer quenching practices, an automatic water-monitoring device known as the Ipsen 'Water Sentinel' is announced by Ipsen Industries Inc., Rockford, Illinois. It is designed for the detection of water in an enclosed-type oil quenching tank used in heat-treating operations.

If moisture in excess of 0·15% is permitted to accumulate at the bottom of an oil-filled tank, or to emulsify in rapidly circulating oil, the possibility of steam formation upon quenching a hot charge within the oil-water mixture becomes acute. The internal expansion can cause foaming and the 1,700 : 1 volumetric expansion of water vapour within the oil can swell the entire volume beyond the limits of the quench tank. This can result, not only in interrupted production, but can also cause extensive damage to equipment.

Water may enter the quench oil system from several sources: (*a*) condensation on cold enclosure walls from high dewpoint atmospheres; (*b*) failure of water-carrying mechanisms within the oil tank; (*c*) careless introduction of water contaminated oil from a storage or reservoir system.

The continuously monitoring detector consists of a detecting probe immersed in the oil and sealed in the tank. A replaceable resistor sensitive to water changes its electrical resistance in the order of 5 : 1 when subjected to emulsion-moisture in excess of 0·1%. This relatively great change permits safe triggering of the alarm system or operation of an automatic shut-off device.

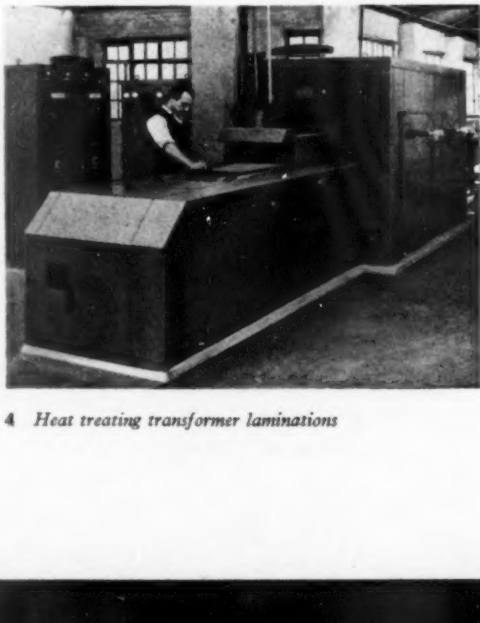
Ipsen Inc. is represented in the U.K. by Mr. T. W. Ruffle, 53 Victoria Road, Surbiton, Surrey.

Heat treatment of transformer laminations

Stress-relief heat treatment of transformer laminations in continuous conveyor furnaces is carried out by the Heat Treatment & Brazing Co. Ltd., Hersham Trading Estate, Surrey. Another furnace with a conveyor belt 36 in. wide is now being built for the firm by Royce Electric Furnaces Ltd., Sir Richards Bridge, Walton-on-Thames, Surrey. Average power consumption in treating laminations in the continuous furnace shown in Fig. 4 is 300 kWh./ton, some 2,800 to 3,000 cu. ft. of town's gas and 370 gal. of water also being required. The reduced time cycle made possible gives considerable power savings and minimizes carbon pick-up, the latter characteristic permitting the use of an inexpensive protective atmosphere derived from town's gas.

Laminations are placed in shallow stacks directly on the conveyor and the steel spacers used in batch treatment are eliminated. Differential thermal expansion within the stacks is avoided by their minimum bulk and by uniform heat transfer from heaters distributed over the roof and hearth of the furnace. The heaters can be controlled in independent banks.

The furnace is used for heat-treatment cycles averaging 60 min. and provides for temperatures up to 1,050°C., an ample margin over the normal working temperature of 820°C. A special entrance chamber to the furnace proper has an adjustable opening to reduce protective atmosphere consumption. Immediately following the heating chamber is a slow cool section leading to a water-cooled zone to bring the work below oxidation temperature before discharge from the protective atmosphere.



4 *Heat treating transformer laminations*

Electrical Aids in Industry *Data Sheet* **No. 8**

Light-Sensitive Cells

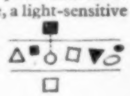
What are light-sensitive cells? They are devices which can sense and measure changes in the level of light or, in some cases, respond to the quality of light falling on them. There are various types of cell and each has its particular field of use. One of the best known is the photo-electric cell.

What can light-sensitive cells do? A change in the amount of light falling on the cell can cause a switch, relay or counter to operate. Alternatively, the direct indication of the light intensity can often allow some other factor to be determined and, if required, controlled. They are reliable and require little maintenance. Careful installation, as with all types of equipment, gives a good reward.

How can they be used? These cells have many applications in industry, for controlling processes, for inspection and measurement, for sorting material and for safety purposes:

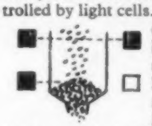
Counting

Where objects on a conveyor belt are too soft or light to operate a direct mechanical counting device, where they are too delicate or freshly painted to sustain physical contact or where the articles vary in size, a light-sensitive cell can be used. This counts the objects by interruption of an appropriately sited beam of light.



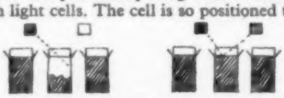
Hopper or Tank Level Control

Many forms of feed can be accurately controlled by light cells. One important one is for controlling the input to a hopper of fluid solids such as sand or peas. Here, two horizontal light beams are required: the upper, when interrupted, indicates that the hopper is full and stops the supply; the lower, when it ceases to be interrupted, indicates that the hopper is nearly empty and restarts the flow.



Package Content

The level of powder in packages can be checked with light cells. The cell is so positioned that



when the powder is up to the required level, the light reflected from the surface of the powder is picked up by the cell and causes the carton to be accepted. If not, it is rejected.

Colour Sorting

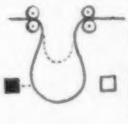
The quality of many articles can be gauged by their colour—seeds and nut kernels, for instance. The objects are fed into a tube by means of a vibrator pan and fall into the beams of three equally spaced light cells which scan them from all sides. If the object is acceptable it falls into a chute carrying it to one conveyor; if its colour is bad it is deflected as a reject.

Guillotine Guard

Light cells for guarding a guillotine or power press should be used only as a supplement to a mechanical guard or where the latter is impracticable. The interruption of a curtain of light by a hand stops the machine instantaneously.

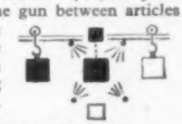
Press Feeding

Where the rate of feed of strip metal must be suited to a varying speed of acceptance by a press, a loop of the strip is allowed to sag between the feed and the press. When the loop reaches a predetermined depth a light beam is interrupted and the slack is taken up.



Processing Objects on the Move

Many articles are processed while on a conveyor line. For instance, where articles are to be sprayed while on the conveyor, the paint saved by stopping the gun between articles will make the device worthwhile. The same principle applies in a bakery to the spraying of baking tins with fat.



Automatic Door Opening and Closing

Doors can be caused to open or close by the interruption of a beam of light. This has its uses in such cases as control of doors on a heating oven or for the passage of vehicles in a factory. This is effected by a light beam on the side from which the approach is made (in many cases, both). When the approach beam is interrupted it opens the door which closes again after a given time interval.

For further information, get in touch with your Electricity Board or write direct to the Electrical Development Association.

An excellent series of reference books are available (8/6, or 9/- post free) on electricity and productivity — "Higher Productivity" is an example. E.D.A. also have available on free loan a series of films on the industrial uses of electricity. Ask for a catalogue.

Issued by the
Electrical Development Association
2 Savoy Hill, London, W.C.2

CUT HERE

5856/6A

Classified Advertisements

FIFTEEN WORDS 7*s.* 6*d.* (minimum charge) and 4*d.* per word thereafter. Box number 2*s.* 6*d.* including postage of replies. Situations Wanted 2*d.* per word.

Replies addressed to Box Numbers are to be sent, clearly marked, to Metal Treatment and Drop Forging, John Adam House, John Adam Street, London, W.C.2.

SITUATIONS VACANT

WEST MIDLANDS GAS BOARD

INDUSTRIAL GAS REPRESENTATIVES

With the increase in the development and utilisation of gas for Industrial purposes, further appointments will be made in the Midlands to meet the demand.

The work will involve investigation and submission of schemes for the use of gas for furnace heating and other industrial purposes.

Applications are invited from candidates with an appropriate university degree, or similar qualification. Experience of Industrial Gas is not essential as adequate training will be given.

The salary during the training period will be in accordance with Grade APT 7 (£733-£813 per annum) of the National Salary Scales for Gas Staffs, and subject to satisfactory completion of the training, appointment to a permanent post on a higher grade will be made. The appointments are pensionable and subject to medical examination.

Applications stating age, education, qualifications and experience, should be addressed to the Industrial Relations Officer, West Midlands Gas Board, Augustus Road, Edgbaston, Birmingham, 15.

J. SWAN,
Secretary to the Board.

GOVERNMENT LABORATORY, Harefield, Herts., require Chemist to take charge of High-Temperature Materials Laboratory with responsibility for high sensitivity creep tests, metallography of titanium and heat-resisting alloys, heat treatment and pyrometry. Qualifications: Hons. degree in metallurgy or Associateship of Institution of Metallurgists or equivalent. Considerable experience in metallography and heat treatment essential. Experience in mechanical testing and creep testing an advantage. Salary: £830 (age 25)—£1,300. Opportunities for establishment. Forms from M.L.N.S., Technical and Scientific Register (K), 26 King Street, London, S.W.1, quoting reference F.711/9A. Closing date December 31, 1959.

METALLURGICAL CHEMIST required for the Analysis of Steels and Heat-Resisting Alloys and Refractories. Applicants should have at least National Certificate or Inter. B.Sc. in Chemistry and be capable of carrying out Analysis without supervision. Age 20-25 years.—Apply to: THE CHIEF METALLURGIST, WILD-BARFIELD ELECTRIC FURNACES LTD., Elecfurn Works, Otterspool Way, Watford.

WANTED

ELECTRIC TEMPERING FURNACE required, suitable for light engineering company. Approx. dimensions 48 in. long x 36 in. wide x 36 in. high. Please send details to Box ET 121, METAL TREATMENT AND DROP FORGING.

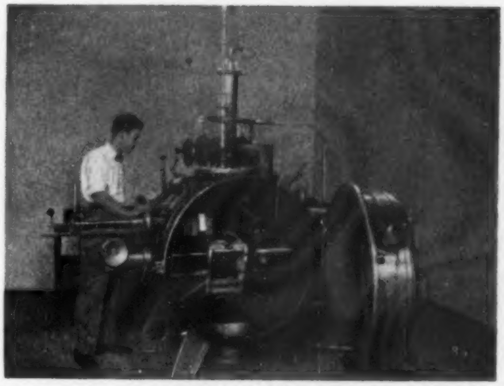
WILD BARFIELD NRC

Vacuum Melting

INDUCTION AND ARC FURNACES

The experience of the National Research Corporation, who have built and operated more high vacuum furnaces than any other company in the world, and the facilities in Britain of Wild-Barfield combine to offer unsurpassed vacuum melting equipment.

Both arc and induction furnaces are available, the former with consumable or non-consumable electrodes, cold mould or skull type. Induction heated equipments include the N.R.C. patented semicontinuous vacuum melting furnaces.



Model 2555 Vacuum Induction Furnace with melting capacity of 50 pounds of steel. Other standard furnaces have capacities of 12 to 3,000 pounds.

INDUCTION HEATED FURNACES FOR...

Melting, Alloying, and Purifying; Centrifugal, Ingot, Shape, and Investment Casting; Sintering, Brazing, Degassing and Heat-Treating.

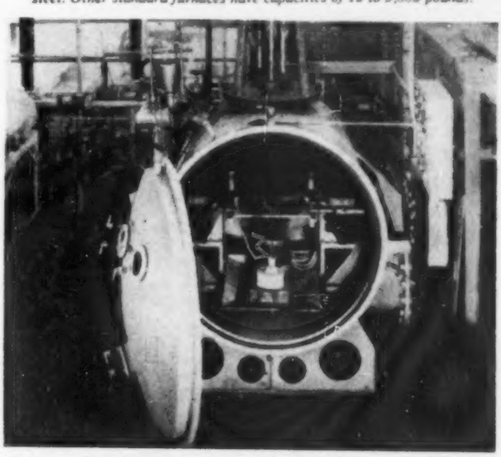
ARC FURNACES FOR...

Melting and alloying high temperature or reactive metals such as niobium, tantalum, cobalt, zirconium and titanium.

OTHER VACUUM EQUIPMENTS

- **Vacuum Fusion Gas Analyser**
- **Hydrogen Analyser**
- **Resistance Furnaces**
- **High Vacuum Diffusion Pumps**

NRC is the trade-mark of the National Research Corporation, registered in the United States Patent Office.



Model 2705 Non-Consumable Arc Skull Furnace with a capacity of 50 pounds of titanium. Other standard vacuum arc furnaces have capacities of 8 to 10,000 pounds of titanium.

ELECTRIC WILD BARFIELD FURNACES

FOR *ALL* HEAT-TREATMENT PURPOSES

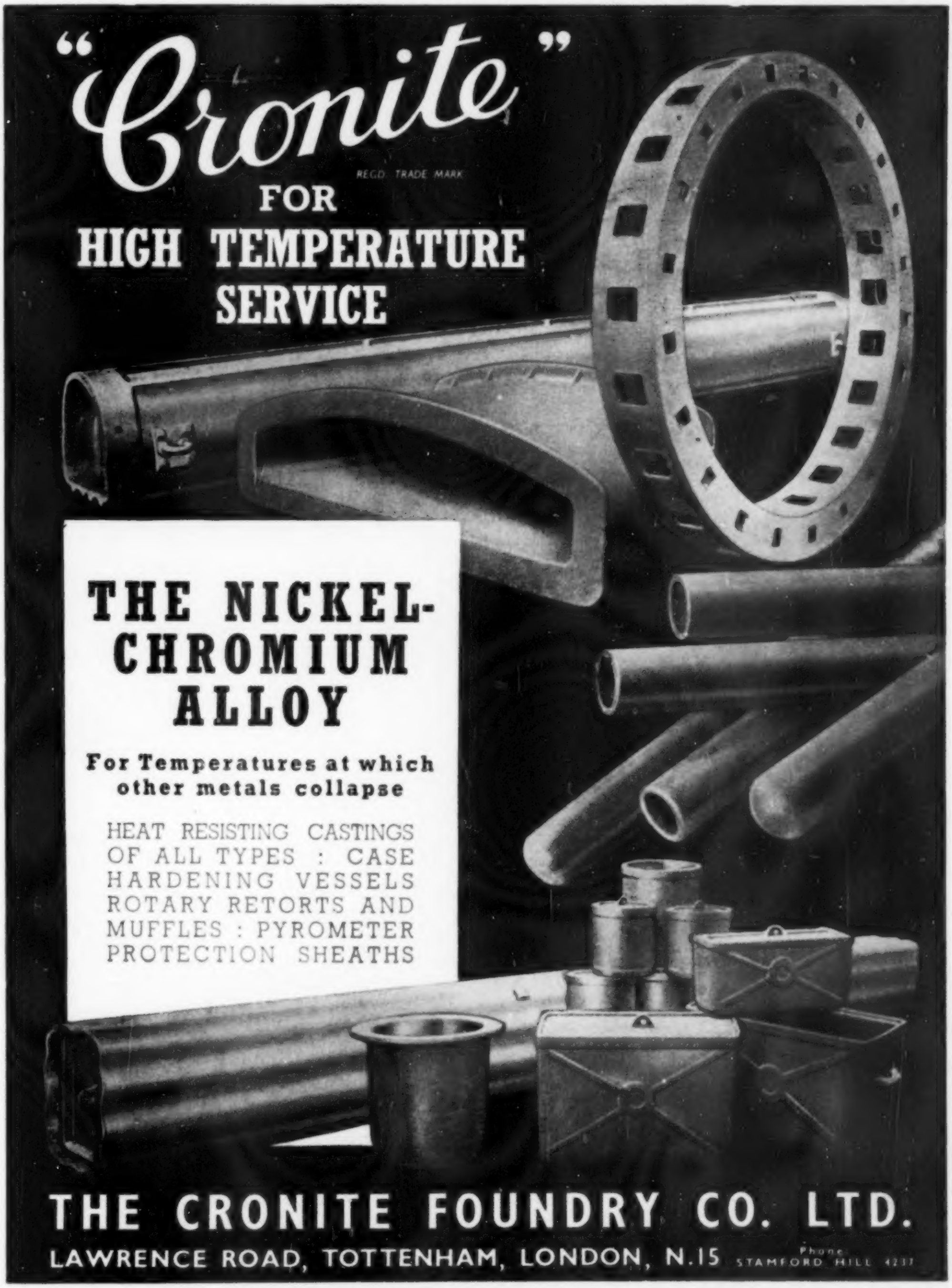
WILD-BARFIELD ELECTRIC FURNACES LIMITED

ELECFURN WORKS, OTTERSPOOL WAY, WATFORD BY-PASS, WATFORD, HERTS. TELEPHONE: WATFORD 26091 (8 LINES)

NRC2

INDEX TO ADVERTISERS

Published by the Proprietors, Industrial Newspapers, Limited, John Adam House, 17/19 John Adam Street, Adelphi, London, W.C.2, and Printed in Great Britain by F. J. Parsons, Ltd., London and Hastings.


"Cronite"
REGD. TRADE MARK
FOR
HIGH TEMPERATURE
SERVICE
THE NICKEL-
CHROMIUM
ALLOY
For Temperatures at which
other metals collapse
HEAT RESISTING CASTINGS
OF ALL TYPES : CASE
HARDENING VESSELS
ROTARY RETORTS AND
MUFFLES : PYROMETER
PROTECTION SHEATHS
THE CRONITE FOUNDRY CO. LTD.
LAWRENCE ROAD, TOTTENHAM, LONDON, N.15
Phone
STAMFORD HILL 4237

metal
atment

Vol. 26 : No. 170 NOVEMBER 1959 Price 2